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THE CHEAPEST POINT OF CUT-OFF.

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Let (HP) = the desired horse-power of the engine.

Let P = the mean effective pressure of steam in cylinder in pounds per square inch.

Let P_b = the absolute initial pressure of steam in pounds per square inch.

Let B = the absolute back pressure of steam in pounds per square inch, exhaust open.

Let e = the fraction of the volume at which steam is cut off.

Let C = the constant charges on engine and boilers in dollars and cents.

Let c = the fraction of the volume of steam used in any convenient period equivalent to the value of the constant charges.

Let b = the fraction of the volume of the steam at which exhaust closes being measured from the opposite end of the cylinder from which e is measured.

Let k = the fraction of the volume of the steam allowed for clearance.

Let V = the volume of the steam cylinder, inclusive of clearance.

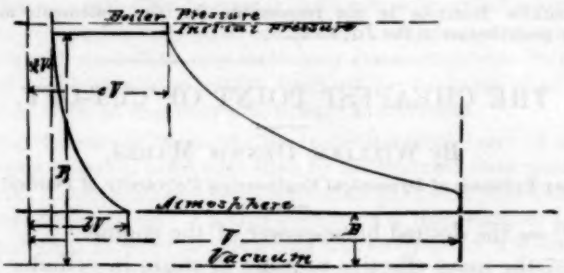
We can then write the following equation:

$$v = \frac{\text{Work}}{\text{Cost of work}} = \frac{\text{Mean effective pressure} \times V}{\text{Cost of steam} + \text{constant charges} - \text{Value of steam saved by compression}} \quad (1)$$

This equation, having for its denominator values in dollars and cents, must be rendered homogeneous.

Since money and steam are convertible, we will take the denominator in volumes of steam.

The best method of obtaining the volume of the steam cylinder (V) and the clearance (k) is to fill the cylinder with water with the crank on the most distant dead point, and then to fill the clearance with water. The weight of water in the clearance, divided by the weight of water in the whole cylinder and clearance, will give the value of k. Reference to the diagram will make this clear.



The mean effective pressure $= P = eP_b \left[1 + \text{nat. log. } \frac{1}{e} - \frac{k}{e}\right] - B\left[1 - b\left(1 - \text{nat. log. } \frac{b}{k}\right)\right]$

For a cut-off e the water used per horse-power per hour is approximately $W =$

$$\frac{859375\ e}{S\left\{eP_b\left(1 + \text{nat. log.}\frac{1}{e} - \frac{k}{e}\right) - B\left[1 - b\left(1 - \text{nat. log.}\frac{b}{k}\right)\right]\right\}} \quad (2)$$

in which $W =$ weight of water evaporated, and $S =$ specific volume of the steam for the pressure P_b.

To find the money value of the steam used we must multiply this value of W by the horse-power, by the number of hours per day the engine is used, and by the cost of steam (*i. e.*, coal and water) per pound.

Equation (1) can be written as follows:

$$y = \frac{PV}{\left[e + c - b\,\frac{B}{P_b}\right] V} \quad (3)$$

for the period of one stroke, and, since the engine can be assumed to make its strokes uniformly, it is equally true for any period of time.

To deduce the value of c, we can write, for the cost of the steam, from equation (2), $W_1 =$

$$\frac{eD}{eP_b\left\{1+\text{nat. log.}\frac{1}{e}-\frac{k}{e}\right\}-B\left\{1-b\left(1-\text{nat. log.}\frac{b}{k}\right)\right\}} \qquad (4)$$

in which the constant $D = \frac{859375}{S}$ (HP) $\times$ hours $\times$ price of steam per pound.

We then can write the following proportion:

$$c : e :: C : \frac{eD}{eP_b\left\{1+\text{nat. log.}\frac{1}{e}-\frac{k}{e}\right\}-B\left\{1-B\left(1+\text{nat. log.}\frac{b}{k}\right)\right\}}$$

Therefore $c =$

$$\frac{C}{D}\left\{eP_b\left[1+\text{nat. log.}\frac{1}{e}-\frac{k}{e}\right]-B\left[1-b\left(1+\text{nat. log.}\frac{b}{k}\right)\right]\right\} \qquad (5)$$

Equation (3) then becomes

$$y=\frac{eP_b\left[1+\text{nat.log.}\frac{1}{e}-\frac{k}{e}\right]-B\left[1-b\left(1-\text{nat.log.}\frac{b}{k}\right)\right]}{e+\frac{C}{D}\left\{eP_b\left[1+\text{nat. log.}\frac{1}{e}-\frac{k}{e}\right]-B\left[1-b\left(1-\text{nat. log.}\frac{b}{k}\right)\right]\right\}-b\frac{B}{P_b}} \qquad (6)$$

Differentiating this equation with respect to e, and seeking a maximum, we have

$$e=\frac{B\left[1-b\left(1\text{ nat. log.}\frac{b}{k}\right)\right]}{P_b}+k-b\frac{B}{P_b}\text{ nat. log.}\frac{1}{e} \qquad (7)$$

Giving a result independent of the constant charges, and dependent only on the initial pressure, the back pressure, and the clearance. It will be observed that the curve of expansion used is the equilateral

hyperbola. This curve coincides, with great accuracy, with the best results derived from indicator diagrams, and we can therefore safely use it until an adiabatic engine is produced for our discussion.

If equations (4) be accurately written

$$W = \frac{\left[e - \frac{Bb}{P_b}\right] D}{P}$$

and used in the following work, we would have the value of e increased by the following numerically small quantity:

$$\frac{C}{D}\,\frac{Bb}{\left[e - \frac{B}{P_b}\right]^2}\,\frac{\left\{eP_b\left[1 + \text{nat. log.}\,\frac{1}{e}\right] - P_b k - B\left[1 - b\left(1 - \text{nat. log.}\,\frac{b}{k}\right)\right]\right\}^2}{P_b^2}$$

Since, however, the quantities in the numerator are all small and the quantities in the denominator give a relatively very large product, we can neglect this term without sensible error. The quantity $\frac{Bb}{P_b}$ is quite small in a non-condensing engine *and can never exceed the clearance k in value.* In a condensing engine it is usually very much smaller. In making close calculations of the water used we cannot afford to neglect this quantity, but it does not sensibly affect the point of cut-off.

The usual and "proper" thing among many of the writers of the present day is to dismiss the isothermal curve with a condemnation and to make use of the adiabatic curve, but unfortunately for this curve it does not agree so well with the actual curve of pressures from our best engines as taken with an indicator, as does the isothermal curve.

If we assume no clearance and no compression, equation (7) becomes

$$e = \frac{B}{P_b} \qquad (8)$$

A law first stated by the writer in the JOURNAL OF THE FRANKLIN INSTITUTE, June, 1880.

The use of equation (7) will be found to give practically correct points of cut-off for non-condensing engines.

A consideration of equation (2) will reveal why it is not possible to carry out this law to its finality in the case of condensing engines.

It is not possible to construct an engine without clearance, or to obtain a perfect vacuum; but if, for the purpose of obtaining an extreme limit, we neglect these, equation (2) becomes

$$W = \text{constant} \times \frac{1}{1 + \text{nat. log.} \frac{1}{e}} \tag{9}$$

If in this we substitute successive values of e, we obtain the successive percentages of water used per horse-power per hour.

$$\text{For } e = 1 \quad \frac{1}{1 + \text{nat. log.} \frac{1}{e}} = 1{\cdot}00$$

$$\text{For } e = \tfrac{1}{4} \quad \frac{1}{1 + \text{nat. log.} \frac{1}{e}} = 0{\cdot}42$$

$$\text{For } e = \tfrac{1}{8} \quad \frac{1}{1 + \text{nat. log.} \frac{1}{e}} = 0{\cdot}32$$

$$\text{For } e = \tfrac{1}{9} \quad \frac{1}{1 + \text{nat. log.} \frac{1}{e}} = 0{\cdot}31$$

The gain by increasing the expansion from eight to nine times is but a theoretical one per cent. at the outside, and possibly there is an actual loss.

In "The Limitations of the Steam Engine," JOURNAL FRANKLIN INSTITUTE, August, 1880, the writer stated as the law of the economical use of steam for $e = \frac{B}{P_b}$

$$W = \text{constant} \times \frac{1}{\text{com. log.} \frac{1}{e}} \tag{10}$$

Under this condition, expansion can probably be carried farther in non-condensing engines perhaps as high as $e = \frac{1}{12}$ to $\frac{1}{14}$. This does not predicate that less steam per (HP) per hour will be used, as will be seen from equation (2).

Regarding condensation, much yet remains to be determined. Perhaps it is not such a gigantic obstruction to progress as we have been led to believe. The pressing need of the present is an intel-

ligently conducted series of experiments on internal condensation in the steam cylinder.

The principles here enunciated apply with equal force to all classes of engines, which can only differ in the amount of condensation, and in their percentage of useful effect.

Mr. Hill's admirable record of the competitive tests made at The First Miller's International Exhibition, Cincinnati, 1880 would show great leakage past the valves and the pistons of the engines of the makers who then exhibited.

The diagrams show the initial pressure before the cut-off was reached to fall so rapidly as to force us to assume the initial pressure to be sustained up to expansion and to compute the value of e.

This can be done by means of formula (2) which gives, when accurately written,

$$\frac{WSP}{859375}+\frac{Bb}{P_b}=e \tag{11}$$

or can be deduced from the mean effective pressure.

$$e=\frac{P+P_bk+B\left[1-b\left(1-\frac{b}{k}\right)\right]}{P_b\left(1+\text{nat. log.}\frac{1}{e}\right)} \tag{12}$$

The values of all the quantities in the latter formula can be formed with practical accuracy from the diagram and engine save e and this can be fixed approximately from the diagram for a first log and the successively nearing values used until the desired accuracy is reached. Logarithms do not vary rapidly so the approximations will be few in cases demanding great accuracy. If by o we denote the percentage of the volume at release we have

$$P=eP_b\left(1+\text{nat. log.}\frac{o}{e}-\frac{k}{e}\right)-B\left(1-b\left[1-\text{nat. log.}\frac{b}{k}\right]\right) \tag{13}$$

The indicator diagram if it can be relied upon would show, in the present case at least, that to neglect o would not introduce so great an error as to use it.

The values of W as given in the table are Mr. Hill's values corrected for the differences in the quality of the steam.

The current practice among engineers of using the terminal pressure to determine the specific volume of steam must necessarily introduce great errors, because the specific volume of steam at low pressures

varies enormously for very slight changes of pressure, and a very small error of either the instrument, or of measurement, will greatly alter the result.

The best experimental method of fixing the point of cut-off is to place an indicator on the steam-chest. A sudden jog in the line will mark the points of opening and closing the steam valves.*

We can then use S for the initial pressure with much less probability of error in the results.

The mean effective pressure can be calculated in the usual way, or taken from the diagram.

Mr. Hill states that "The steam per hour by the diagram is the weight of steam to release less weight for steam retained for cushion."

If, however, we make the calculation of steam at initial pressure, we have, as already stated

$$W = \frac{\left(e - \frac{Bb}{P_b}\right) \times 859375}{SP} \qquad (14)$$

The following summary is taken from Mr. Hill's Report, and is only changed in form so as to render the application of the formulæ convenient.

	Condensing Trials.			Non-Condensing Trials.		
	Reynolds Corliss.	Harris Corliss.	Wheelock.	Reynolds Corliss.	Harris Corliss.	Wheelock
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Barometer	14·56	14·47	14·31	14·58	14·47	14·44
P_b Initial press., ab.	105·65	104·55	102·40	104·57	103·99	102·94
Back pressure, abs.	4·45	3·35	4·71	15·33	14·80	15·40
Mean effective pres.	35·40	35·67	33·94	29·78	28·94	29·36
Wt of st pr HP pr hr	14·067	13·755	13·762	17·420	17·220	19·674
Specific volume	255·07	257·49	262·28	257·49	258·70	260·90
Ind. H. P.	162·99	165·58	158·38	137·02	134·29	139·97
Clearance	·0258	·0189	Exp ·023 Com ·014	·0258	·0189	Exp. ·023 Comp. ·014
Exhaust closes	·08	·1382	·0552	·1065	·1365	·0968
Exhaust opens	·952	·922	·935	·956	·952	·956
e — Mr. Hill's. From diagram	·150	·144	·157	·185	·157	·194
e — Calculated from formula 11	·151	·151	·147	·171	·170	·190

* Suggested by J. Sellers Bancroft.

It will be noted that the order of rating in economy of weighed steam from the boilers at the trials of Mr. Hill is precisely that given by the computed values of e.

It will further be noted that the engine having the lightest load, and consequently the earliest cut-off was the one awarded the greatest economy of steam in the several trials, noncondensing and condensing.

The excess over the others of $\frac{26}{100}$ of an inch in the bore of Mr. Wheelock's engine was not an error which diminished the probability of great economy of steam, but the fact of its having the heaviest load and the least initial pressure in the non-condensing trial brought the economy of the engine below that of the others, although this engine was awarded the greatest economy in the condensing trial in which it had the lightest load and the earliest computed cut-off, but not the was greatest initial pressure. The Harris-Corliss, for the same reasons, was awarded the greatest economy for non-condensing. These points are of value as bearing directly on the question of increase of economy with greater expansions.

The value of e giving greatest economy of steam under the assumptions as to the expansion and neglecting o can be computed from equation (7), and the water per HP per hour can be computed from *Eq* (14).

TABLE OF LIMITING MINIMUM VALUES—COMPUTED.

	Condensing.			Non-Condensing.		
	Reynolds Corliss.	Harris Corliss.	Wheelock	Reynolds Corliss.	Harris Corliss.	Wheelock
Minimum cut-off, e_0	·059	·042	·069	·151	·139	·160
Minimum mean eff. pressure, P_0	16·53	12·51	18·25	26·45	24·67	27·47
Minimum weight of water per H.P. per hour, W_0	11·22	10·14	11·97	16·83	16·80	17·50
Minimum H.P.	above 75	above 46	above 95	119·	116·5	131·

All of these calculations have been made under the assumption that the steam weighed from boilers is all accounted for by the diagram, which is not absolutely true, but would seem from Mr. Hill's results to be proportionally true with a close approximation, since the proportion of weighed steam [calculated from volumes of water] was to the steam shown by the indicator as 4 to 3 or thereabouts for both condensing and non-condensing engines.

These experiments are utterly valueless for the purpose of determining the amount of condensation, since these engines, presumably made with all the care and skill of experienced makers, leaked so badly when warmed up that the clearance could only be gotten approximately.

In the matter of the proportion of water accounted for by the indicator, we should have a series of experiments conducted with every precaution observed by Mr. Hill, but the steam pressures should be varied through a wide range.

For each steam pressure the point of cut-off should be varied throughout the stroke at regular intervals of say one-tenth or less, and of course, the load with it. In fact it would perhaps be best to use an automatic cut-off and vary the load, leaving to it the adjustment of the cut-off.

The thermal values of the steam must be most scrupulously determined at the boiler, at the steam-chest and at the exhaust.

Leaks at the piston could be almost perfectly prevented by simple temporary precautions as to the piston packing during the experiments.

Finally, each set of experiments should be made sufficiently long to eliminate accidental errors. Particular attention should be paid to the indicator, as its errors are sometimes greater than would be believed when in good (?) working order, and when out of order, or in any way dirty, it is utterly valueless. Something better than any of our present indicators must be devised to be of any accurate scientific value or to obtain the faith of any one save for rudely approximate work and for everyday practice in steam engine designing.

Fortunately this difference of actual and indicated steam does not affect the point of cut-off materially in most cases. The exception may arise with great compression.

The actual conditions as to back pressure (B), clearance (k), and compression (b) are not altered in the last computations.

The results in the last table are obtained by the use of the following formulæ:

$$B_1 = B\left[1 - b\left(1 \text{ nat. log. } \frac{b}{k}\right)\right]$$

$$e_0 = \frac{B_1}{P_b} + k - \frac{bB}{P_b} \text{ nat. log. } \frac{1}{e_0}$$

$$P_0 = P_b\left[e_0 + e_0 \text{ nat. log. } \frac{1}{e_0} - k\right] - B_1$$

$$W_0 = \frac{859375\left(e_0 - \frac{Bb}{P_b}\right)}{P_0 S}$$

$$\text{Minimum and cheapest horse power} = \frac{P_0}{P} \times \text{Indicated HP.}$$

The dimensions b and k are more accurately taken from the engine than from the diagram, which, while giving a good average, is rarely exact at any particular place.

The theoretical minimum results for condensing trials are not closely calculated because they do not surely indicate accurate attainable results, but serve merely to show in what direction progress must be made.

Right here our knowledge is deficient, and we must have more data regarding condensation before attempting to accurately predict real results at high expansions.

Concentration of power is lost with increasing economy of steam. It is a very important attribute of the steam engine, bearing directly upon its efficiency as a machine.

Mr. Hill's experiments on the condensing engines prove most conclusively, within the narrow limits as to expansion which he set by his conditions of trial and size of engine cylinders, that increased expansion meant increased economy of steam. Even with the slight variations of load and steam pressure which he could hardly have prevented, his award as to economy of steam was a matter of chance.

It is not worth while to reopen a much disputed question by making the proper correction so as to show which really was the most economical engine.

With the method of testing used, without corrections, any one of these evenly-matched engines could have apparently shown itself the superior with slightly favoring conditions or variations in the load or the initial pressure.

The influence of compression and clearance and of condensation may be discussed in a future paper.

Those interested in condensation and its causes should read the researches of M. Hirn, translated by Prof. Smith, in the *Journal of the Association of Engineering Societies*, Nos. 1, 8, 9, 10 and 11, of Vol. I, and Nos. 3 and 7 of Vol. II.

It is to be regretted that no readily applicable law of the condensation has been developed by his work. One point is clear, a very large condensation usually occurs with saturated steam.

In closing this already too long paper, we would add that we do not wish to create the impression that Mr. Hill has omitted any known precautions or has been lacking in skill or vigilance. It is the great superiority of his records, and his careful attention to every detail, that has enabled us to verify our own mathematical investigation of the physical action of steam. The writer is under very great obligation to him.

Philadelphia, November 6, 1883.

EXPERIMENTS UPON NON-CONDUCTING COVERINGS FOR STEAM PIPES.

By Prof. John M. Ordway, Boston, Mass.

[Read before the American Society of Mechanical Engineers, November, 1883.]

In undertaking an investigation of steam pipe coverings it was necessary, in the first place, to decide what method or methods should be used for determining their efficiency as non-conductors of heat. I have met with no recorded experiments of which the details are given in full, but it seems that, in general, two modes have been heretofore employed. In one—the air chamber method—a portion of the covered pipe, while in use, is inclosed in a small box so as to form a close chamber into which the bulb of a thermometer is inserted. The inverse ratio of the temperatures indicated by the thermometer in different trials is supposed to show the relative excellence of the different coverings.

In the second, or condensation method, the steam is allowed to pass from the main pipe out into a side branch covered with the substance in question, and so arranged that whatever water is formed in an observed number of minutes may be drawn off from time to time and weighed or measured. The water is reckoned as having parted with as much latent heat as is contained in that weight of dry steam.

As to the air chamber method, it might be thought easy to carry out, but it is difficult to fit a box of any kind so closely to the covering that there will be no circulation of air into and out of the inclosed space. Of course, a lack of tightness will fatally vitiate the experiment. Again, a box surrounding the pipe and covering, presents a

large radiating and cooling surface as compared with the covering itself; and there is no ready way of determining the amount of this continual radiation which increases with the temperature of the air within the chamber. There is no perfect non-conductor wherewith we can surround the air chamber, so as to confine therein all the heat received. If we could prevent all outward radiation, the cavity would sooner or later acquire the temperature of the steam in the pipe, and all coverings would finally give the same results. The only way to make useful observations would be to start with everything cold, and find the time required to raise the air in the chamber to a given temperature. This is, however, hardly practicable.

We cannot obtain absolute or quantitative results by this method, and the comparative figures require indeterminable corrections. Still it was thought advisable to try this plan among others, and see how far the results would correspond to those found by more definitive modes. Accordingly, an apparatus was devised and used for this purpose, consisting of pieces of white pine plank, squared and rabbetted at the ends, to which wooden braces were firmly screwed on. A two-inch tube was bored from the inner side, two-thirds through, to form a cylindrical chamber. The inner side was then planed out so that the concavity, when properly lined should exactly fit the covering to be tried. A hole was bored from the top edge into the cylindrical chamber, and concavity and chamber were both lined with a thick woolen blanket.

When used for testing, the halves are clamped on the pipe-covering with four iron rods and tightened to a close fit with thumb nuts. Thermometers are let down into the chambers, a little cotton wool being crowded in around the stems, to prevent the ingress of cold air.

The two chambers so applied serve to check each other; for if the thermometers differ much, there is a defect in the adjustment. A difference of two or three degrees, however, may occur, on account of an inequality in the two sides of the covering itself.

The condensation method is indirect, and therefore a little uncertain. It necessarily assumes that the pipe is all the time filled with dry steam. But we can hardly expect to have pure steam when its generation is going on rapidly, and the vapor passes off through a long pipe which is all the time radiating heat. We can justly expect only a mixture of real steam with more or less mist. And if this mist, which has already lost its 500° C. of latent heat, is reckoned as invisible steam, our figures will not give the exact truth.

And then again, besides the two or three feet of pipe with the covering to be tried, there are necessarily the cap and other fittings which will lose heat in spite of any wrapping that we may put around them. The gross results, therefore, need to be corrected by the amount due to the condensation by that portion of the branch which is not protected by the covering. It is quite possible to find the amount of this correction, if one has the material of the covering so that he can apply it himself and make it uniform. Thus we may cover, say three feet of pipe, wrap the fittings with a good non-conductor, and make trials enough to get a fair average. Then we may cut off one foot of the pipe and covering, keeping the other parts and their wrappings exactly the same as before, and make a second series of trials. Now, let x be the amount of condensed water due to the three feet of coating, and y that due to the fittings. Having found for one hour $x + y = a$, by the first trials, and by the other set $\frac{2x}{3} + y = b$; by combining these equations we get $x = 3\,(a—b)$; and $\frac{x}{3} = a—b =$ condensation per foot per hour.

If cutting the pipe is not feasible, the deduction to be made may presumably be ascertained in another way. First, determine the whole condensation by the covered pipe and the well wrapped fittings. Secondly, strip off the covering and try the naked pipe with the wrapped fittings. Thirdly, wrap the pipe just like the fittings and make more trials. Lastly, strip off the wrappings from pipe and fittings and try all naked.

Now let $x =$ the amount of condensation by the naked pipe alone; $y =$ that by the naked fittings; $z =$ that by the wrapped pipe alone; $w =$ that by the wrapped fittings; and $u =$ that by the covering in question.

By the last determination above mentioned we have found $x + y = a$; by the second, $x + w = b$; by the first, $u + z = d$; and by the third, $z + w = c$. We may fairly assume that $x : y :: z : w$, or $xw = yz$. Then by the various eliminations and substitutions, we have

$$x = \frac{a\,(b-c)}{a-c};\quad y = \frac{a\,(a-b)}{a-c};\quad w = \frac{(a-b)\,c}{a-c};\quad z = \frac{(b-c)\,c}{a-c};$$

$$u = d - \frac{(b-c)\,c}{a-c}$$

In an actual trial, the result of which is given in No. 25 of the appended table, the slag wool enclosed in straw board, supported by plaster rings at the ends, made altogether a covering 21 inches long. The extra pipe and the fittings were well wrapped with cotton wool, and the condensation was found $d = 108{\cdot}6$ grams per hour. Removing the slag wool covering, it was found that $b = 354$ grams. Replacing the covering by cotton-wool wrapping, it appeared that $c = 105{\cdot}3$ grams. With all wrappings stripped off, it proved that $a = 428$ grams.

Hence, by substituting these values in the above formulæ, we find $x = 316{\cdot}7$; $y = 111{\cdot}3$; $w = 27{\cdot}3$; $z = 77{\cdot}7$; $u = 81{\cdot}3$. Then $\frac{12}{21} \times 81{\cdot}3 = 46{\cdot}5$ grams per foot per hour.

[For making trials by condensation, the author showed drawings of, and described an arrangement, consisting of the mean steam pipe; a T by means of which the steam may pass freely through the nipple, and an elbow into a branch pipe with its covering. A bit of India rubber tube, attached to a stop cock connected with a cap, allows the condensed water—when the cock is opened a little—to pass into a glass flask without direct exposure to air currents. All of the uncovered parts of the branch pipe are wrapped with cotton wool. The angle of inclination is such that whatever condenses in the elbow runs back into the main pipe, unless it remains suspended as mist, and is swept forward.]

As to the question of mist, I see no way of settling it except by combining the condensation method, including the correction given above, with the calorimetric method now to be described.

The calorimetric method, besides being direct and absolute, seemed to me to promise a closer approximation to the truth than any plan used hitherto. To carry it out, a contrivance, specially devised by the author, was provided of different sizes to suit different coverings.

[There was shown a transverse section of the pipe, covering and a pair of calorimeters, a longitudinal section through a portion of the apparatus, an end view of the calorimeter, and a view of the same as seen from above.

The calorimeters are made of sheet brass No. 29, and are so shaped that when clamped together they may completely and closely include a portion of the pipe covering. A tube serves for the introduction of water, and the subsequent insertion of the thermometer, which is

retained in place by a perforated cork. Another pipe in the bottom serves for drawing off the water by removing the cork. A glass tube, attached by a caoutchouc connector to a small brass tube in the end, shows the height of the water. The top piece, to the inner sides of which are soldered slotted brass plates, allows a wooden paddle to be swung back and forth on a brass pin, to equalize the temperature of the water. The perforated brass ears and the binding rods, with the thumb nuts, furnish the means of clamping the two halves over the pipe covering. Thick wooden washers give a chance to turn the thumb nuts past the edge of the slanting bottom.

A different mode of clamping was described by the author and illustrated in perspective and sectional views. In this, pine wood braces, held together by bolts, are distinct from the calorimeters. This mode of clamping was actually used in most of the experiments, but the wooden braces were not so easy to manage, and they were much in the way of the wrapping; for in use the whole apparatus was covered with cotton batting put on thick and held on by cotton twine wound around in various directions. Cotton wool makes a good and cheap covering, but it takes much time to apply it. Latterly, it seemed best to try other wrappers, and for the sake of greater compactness a modification of the apparatus was constructed, in which long sheaths receive the wooden rods, which are held by pins at one end and wooden wedges at the other. A calorimeter of this form was surrounded by a box of thin wood made much larger, so as to leave a space about $1\frac{1}{2}$ inches thick all around the brass boxes—two pipes and the top piece, as well as the gauge, projecting outside the wooden box. The space was filled with nearly two pounds of live geese feathers. The feathers make an excellent non-conductor, but they are rather expensive, and by no means easy to handle.

Then a modified form of clamping arrangement was tried, and a cover was made of three thicknesses of very soft woolen blanket sewed on; this is rather costly, but it is, perhaps, the best wrapper to use. A wrapper of hair-felt was tried twice, but it was too tender to be used many times, and it did not admit of sewing on, but had to be held on with twine wound around.]

In making trials, the calorimeters are filled up with water 10° or 12° C. colder than the air of the room, the thermometers are inserted and the water is well agitated with the paddles. The temperature of the water, the steam pipe, and the air of the room, and the time are

noted. Observations are made every half hour, or oftener, till the water stands 10° or 12° higher than the surrounding air. The water is then drawn off and weighed. The experiment is repeated times enough to give a fair average.

Of course, all the heat transmitted by the length of pipe covering enclosed by the apparatus is taken up by the water, and could be exactly determined were there no radiation from the calorimeter itself. But wrap as we may, there will still be a loss when the surrounding air is colder than the water. To neutralize the error from this source we should use only that part of the experiment which lies between two observations, in one of which the water is about as many degrees colder than the air as it is hotter in the other; thus, the absorption of heat from without in the first part of the time is balanced by the radiation from within in the latter part.

The calorimeter itself takes up heat as well as the contained water, and we must, therefore, add to the weight of the water as much as corresponds to the weight of brass and immediate surroundings, the specific heat being taken into account. For every calorimeter this is a constant quantity which may be determined practically by mounting the apparatus on an unheated pipe, wrapping it as usual. Cold water is run in and allowed to stand some time, the temperature being noted. Then the water is as quickly as possible run out and replaced by warm water of known temperature. After a thorough agitation the temperature is observed, and the warm water is drawn off and weighed.

Let t = the temperature of the cold calorimeter.

t' = the temperature of the warm water at first.

T = the temperature of the warm water after it is run in, and a = the quantity of warm water drawn out and weighed.

If x = heat units taken up by the calorimeter, reckoned either in grams of water heated 1° C. or in pounds of water heated 1° F.; then

$$T = \frac{a t' + t x}{a + x}; \text{ hence } x = \frac{a(t' - T)}{T - t}$$

In an actual trial, the water equivalent of the calorimeters A I, A II was found to be 194 grams for each.

In an experiment with covering No. 34 of the table hereto appended:
At 9 h. 15 m., A I stood at 12·63° C., and A II at 12·64°.*
At 3 h. 25 m., A I stood at 42·73°, and A II at 42·18°
Mean temperature of the air, 27·7° C.
Interval 370 minutes.
From A I were drawn off 3,260 grams of water; from A II 3,320 grams.
Calculating from these data:

$$(42{\cdot}73 - 12{\cdot}63)\ (3{,}260 + 194) \times \frac{60}{370} = 16{\cdot}859°.$$

$$(42{\cdot}18 - 12{\cdot}64)\ (3{,}320 + 194) \times \frac{60}{370} = 16{\cdot}833°.$$

The average of these and trials made on two other days, was one kilogram of water heated 16·671° C. per hour in each calorimeter. But the two brass boxes include 14 inches in length of the covering.

Hence $\frac{12}{14} \times 2 \times 16{\cdot}671 = 28{\cdot}579$ kilogram-centigrade heat units, or one kilogram of water heated 28·579 C°. per hour by each linear foot of the covering. To reduce this to pound-Fahrenheit heat units, we multiply by $\frac{9}{5} \times 2{\cdot}205$, which gives 113·43° per foot per hour.

Thus we have an absolute measure of all the heat which is transmitted by the covering. But it may, with some reason, be objected that the rapidity of transmission, and therefore the amount of heat passing off from a constant source in a given time, is influenced by the temperature and nature of surrounding bodies; and hence that the communication of heat to a fixed quantity of water is not necessarily the same as that actually given off to air in free circulation. Farther experiments are needed to determine exactly how the heat imparted to the water calorimeters compares with that given out to air by the freely exposed covering. We should naturally expect that as water has a higher specific heat than air it would induce a more rapid cooling, and that therefore the water calorimeter would give higher results

* Though throughout this report many temperatures are expressed in degrees with two decimal places, it should be understood that these are not actual readings, but in most cases the observed numbers have been corrected according to the calibration table of each thermometer; and in calibrating, it was thought as well to carry out the calculations to hundredths of a degree.

than the condensation method. But we have a limited quantity of water allowed to get pretty warm as compared with an unlimited supply of cold air. In fact the coverings No. 24 and No. 25 of the appended table were intended to be alike, and were very nearly so. As the temperature of the steam averaged 150° C., its latent heat was 500° C. Now the quantity of water condensed per foot per hour in No. 25 was 46·5 grams. And $46{\cdot}5 \times 500 \times \frac{1}{1000} = 23{\cdot}250$ kilogram-centigrade heat units, while the calorimeter trial of No. 24 gave 22·807°. The difference is not large, and this tends to show that air-cooling and calorimeter-cooling are not very unlike.

Any uncertainty as to whether water calorimeters show the actual loss of heat by pipe coverings does not affect their comparative indications respecting different coverings. A more important matter, perhaps, is the not unfrequent impossibility of exact fitting. Coverings that are plastered on are never of uniform thickness, nor are they exactly cylindrical. In such cases the contact of the calorimeters will be more or less imperfect, and radiation through confined air will be partly substituted for direct conduction. On the other hand, yielding coats, like hair felt, are somewhat compressed by clamping on the brass boxes, and yet more by the weight of the filled apparatus; and the more closely fibrous matter is compressed, the greater its transmitting power. So the results of the trials are likely to be somewhat too favorable to the hard and inelastic coverings.

In carrying out the examination of pipe coverings, it seemed best to get samples such that each one could be used for the three methods in succession. Accordingly, circulars were sent out requesting manufacturers and others interested in the subject to furnish whatever specimens they wished to have submitted to competitive trial. The directions called for pieces of ordinary two-inch steam pipe two feet long, cut with a right-hand thread at each end, and then covered, in the usual way, for a length of eighteen inches between the threaded ends. In response to this invitation, thirty-one samples were sent in by various makers, and eight kinds were brought and applied directly to our hot steam pipe in place. In only one or two instances have prices been given.

The room available for the experiments is an iron turning shop, through the upper part of which runs thirty-six feet of two-inch pipe, conveying to an engine steam of sixty pounds pressure. The engine

is run in term time, from 8.45 A. M. to 12 M., and from 1.30 to 4.30 P. M. During the noon hour the pipe is full of hot but not moving steam. Before entering the room, the pipe runs about 110 feet from the boiler. Two lengths of the pipe in the room were taken out and replaced by as many as possible of the two-foot sample pipes coupled together. Near the middle of a set was inserted a T with a three-quarter inch side connection turned upwards. Into this was screwed a bushing furnished with a long thimble reaching nearly to the bottom of the T inside. [A longitudinal section of this disposition was exhibited showing the T; the plug; the thimble, made of a piece of three-eighths inch gas pipe capped and filed thin. A thermometer suspended in the thimble by means of the perforated cork, gives the temperature of the passing steam.]

Calorimeter and air chamber trials were made with each covering two, three, or sometimes four successive days. When one set was gone through with, another set was mounted in their place. But several of the samples had been so covered as to leave too little space for a good grip of the pipe wrench, and therefore could not be dismounted in fit condition for connecting again as side branches. Moreover, the number of specimens sent in was unexpectedly large, some makers furnishing many pieces differing more in size than in kind. Hence it was necessary to be content with setting up again for the condensation trials only such uninjured pieces as might represent the different types of coverings.

When the experiments with each piece were finished, the cover, while still at its maximum of dryness, was stripped off, dissected, and weighed; for, of course, the non-conducting power is not the only thing to be considered. We must take into account the cost, weight, bulk, necessary thickness, durability, ease of application, ease of removal, repair and renewal, simplicity, appearance, freedom from smell, temptation to insects or mice, hardness, resistance to moisture, combustibility, liability to crack, and the possible chemical effect on the pipe.

Pipe coverings may be divided into four general classes:

1. Those consisting essentially of light fibrous matter, as hair, slag wool, or paper, applied immediately to the pipe.

2. Those composed of a paste or mortar, which is plastered directly on the pipe, in one or several coats.

3. Those having an air space next the pipe.

4. Complex combinations of different layers.

It will be seen that of all the coverings tried, as shown by the annexed table, the most efficient was simple hair felt with a cheap cover of burlap. It appears also that of the whole number, seventeen owe their efficacy to hair.

Slag wool came third in rank; but it should be noticed that this was a most remarkable covering. The slag wool was two inches thick and was surrounded by wooden slats one inch thick, these being covered with three thicknesses of cloth. So the whole was enormously and absurdly bulky. On the other hand, this wool was not of commendable quality, for it parted with 38 per cent. of heavy globules when it was thrown on a sieve, and this superfluous portion had increased the weight without doing any good. A more feasible covering was tried in Nos. 24 and 25, with the very same fibre after sifting out the shotted slag. This one inch coating showed a fair result, though of course, by long heating and sifting and handling, the fibre had become much broken, and could not therefore be as efficient as new wool. It was desirable to try new slag wool, of the best quality, but the dealers in the article were unwilling to sell a small quantity. No doubt the best kind would give a more favorable result than that shown in No. 24, and would prove really more economically than the cheap sort. I suppose this latter kind is the same substance that is known in England under the misleading name of "silicated cotton."

Spongy paper, as in No. 16, proves to be a tolerable good non-conductor. In a condensation experiment not given in the table, Reed's covering gave a net result of forty-six grams per foot per hour, which almost coincides with that of slag wool in No. 25.

Straw covered with cotton cloth, as in No. 28, does not show an encouraging degree of excellence.

The otherwise useless rice chaff of No. 18, moistened with water-glass to make it less inflammable and somewhat coherent, proved much more efficient than straw rope.

It should be remembered, fibrous or porous matter acts mainly by virtue of entrapped air, and hence the looser it is the better. Thus everybody knows that hard-spun woolen stuffs do not make warm clothing. Asbestos is commonly supposed to have wonderful virtue in resisting heat, but there is really no magic power in the mineral fibre. It is a non-conductor only when it is in a light, downy condition and full of air. The figures given in No. 50 show that hard-

pressed asbestos paper conducts heat very readily. And it was observed that in those cases in which asbestos paper is put between the pipe and hair felt, the asbestos fails to prevent the scorching of the hair. Incombustibility should not be confounded with non-conducting power.

As to the second class, the plastered coverings, none seems to be worth much except the diatomaceous earth or "Fossil Meal," of Nos. 21, 26 and 27. Of only one or two of them was the exact composition known, but there is not one of such excellence that the secret of its composition is worth keeping. Most of the pastes have an admixture of hair, vegetable fibre, or asbestos, to make them tougher and keep them from cracking. The more organic fibrous stuff can be worked in the better, for it makes the covering lighter and looser and hence less capable of transmitting heat. When such fibres are surrounded by clay, plaster, or other mineral matter, it makes little difference whether they are of themselves combustible or not; they cannot char or burn unless used in connection with steam of extremely high pressure, or super-heated steam. So here again, as compared with animal or vegetable fibres, asbestos, which is really a heavy mineral, has more plausibility than positive virtue. Most of the makers of plastered coverings appear to have been experimenting with materials that are too dense.

To the third class, those with greater or less air space, belong Nos. 9, 12, 19, 20, 22, 23, 34 and 37.

With regard to the efficiency of coverings with an air space, the experiments so far are not decisive, because in no two trials was it certain that the material was otherwise of precisely the same quality and thickness. In Nos. 34 and 36, which were apparently the same, with the exception of an additional wire gauze support in No. 34, the air space showed but a very slight advantage. The comparison of Nos. 16 and 19 is even unfavorable to the narrow air space.

But when there is no visible covering at all, as in Nos. 47, 48 and 51, it makes a wonderful difference whether the calorimeter comes in direct contact with the pipe, or a thin stratum of air intervenes. It seems, too, that a quarter of an inch of air is as good as an inch. This calls to mind the well-known fact that one may safely stay a few moments in the air of a room heated to a point much above the boiling-point of water, as in the old "hot room" of calico print works; but

if the skin touches a metallic body or a liquid of the same temperature, burning or scalding ensues.

So it was also observed that when hair or paper remained for a considerable length of time in contact with the hot steam pipe the organic matter became browned or scorched, while the hair felt in No. 9 remained, to all appearances, entirely unchanged, except at the ends where it was gathered in and touched the pipe. It might be thought that the bright tin plate case, as such, had something to do with preventing the scorching; for, from the tradition of Leslie's old experiments on heat, a surface of bright tin is reputed to be a poor radiant and recipient. But when the mere tin case of No. 9 and the straw-board case of No. 20 were put on the pipe, side by side, the tin box soon became hotter than the hand could bear, while the straw-board could be handled.

An air space, then may prove very useful in obviating one of the great objections to coverings of organic fibrous matter, though it is not specially beneficial in other respects. Woolly asbestos or asbestos paper, which the makers of some of the specimens appear to have relied on for this purpose, does not accomplish the object, for in all those samples in which a wrapping of asbestos came between hair and the pipe, the hair, after the trials, was found to be discolored by the heat. And then again, experiments Nos. 47 and 50 show that a wrapping of asbestos paper does not insulate so well as the same thickness of mere air. The popular confidence in asbestos partakes of the character of a superstition.

Coverings of the fourth class, those made up of many layers of different kinds, have not proved better or more efficient than the simpler ones; and we may justly set down much of the ingenuity shown in devising coverings of this class as fruitless. Of course, complexity enhances the cost, and there should be some corresponding advantage.

But of the actual prices charged, I have received statements in only one or two instances. It is evident, however, from the labor necessarily required to produce some of the specimens, that cheapness has not been kept sufficiently in mind. The question as to whether a covering shall be used or not is one mainly of dollars and cents, and the inquirer must be satisfied that the saving of heat will soon make up for the outlay.

From No. 51, it appears that a naked two-inch pipe, carrying sixty pound steam, may condense 181 grams per foot per hour, and No. 25

shows that a cheap covering may reduce this to 46·5 grams, making a saving of 134·5 grams per hour, or 1·345 kilos. = 2·96 lbs. of steam in a day of ten hours. So the covering of one hundred feet of pipe would save in a year of 300 working days, coal enough to convert 88,800 lbs. of water into steam. If we consider one pound of coal as capable of making 8·88 lbs. of steam, we shall have a saving of five tons of coal per year for one hundred feet of the covering. So, where coal is worth $5 per ton, it would certainly be worth the while to use a covering costing not more than twelve cents per foot, but we might wish to think twice before taking one worth twenty-five cents per foot.

In some cases it may be worth the while to add a little to the expense for the sake of securing a good appearance and having a covering that can be easily kept clean. An encasement of cotton duck or canvas looks well, whether the cloth is drawn together by the edges and stitched, or is torn into narrow strips and wound around spirally. Except the costliness of this closely woven stuff, the only objection to such a jacket or bandage is its combustibility, and this ought to be obviated by painting the canvas with water-glass. Some of the plastered coverings sent in have a hard, smooth exterior finishing coat, which gives a pretty appearance, but adds too much to the already excessive weight.

The weight and bulk of a covering are of some consequence, for if we add to the pipe three or four times its weight or size of other matter, we make it troublesome to support. A coating over five inches in diameter for a two-inch pipe seems absurdly disproportionate; and as the pipe itself weighs fifty-six ounces per foot, an additional weight of sixty ounces or more is altogether beyond reason. The weights given in the table show that some makers have sinned grievously in this matter. In the large and heavy specimens tried, excepting No. 3, there appears to be a lack of efficiency, and there is little else to commend them.

Of course, for every kind of covering there is an optimum of thickness beyond which the cost and bulk of any addition is not compensated by any further gain in efficiency, and this best size can be approximately determined only by a series of careful experiments with each particular substance or composition. As most of my trials have been of ready-made coverings furnished by others, there are few data for reasoning about the matter of thickness. In comparing Nos. 1

and 2, we see that an increase of hair beyond an inch of thickness, or thirteen ounces of weight per foot does very little good.

Nos. 27 and 35 were made with the same fossil meal paste, and put on by the same person; and here we see that a much less thickness than one inch of fossil meal is insufficient.

Though Nos. 3 and 24 are not strictly comparable, the two taken together go to show that when poor slag wool is used it will pay to have it considerably more than an inch thick.

As to ease of application, repair or renewal, Reed's covering, Nos. 16 and 19, and the Chalmer Spence Co.'s complex tubes, Nos. 6, 10, 12 and 17 stand foremost. These are molded into form and partially bisected lengthwise—Reed's so as to leave merely a thickness of paper for a hinge, and the Chalmer Spence through one side of the hollow cylinder—so the tube has only to be opened or sprung apart somewhat, clasped over the pipe, and fastened together at the meeting edges with double pointed tacks. The covering can be taken off at any time by taking out the tacks and prying the joints apart. Next to these comes hair felt which can be cut of suitable width, clasped around the pipe, and held on by winding string or fine wire around spirally. It may be left so, or cloth can be sewed on around it.

Straw rope can be wound around spirally at a pretty rapid rate, but in time it becomes so brittle that it is worthless when unwound again.

In No. 37, the tin plate cylinders are made in halves which lock together and are more easily put on than taken off. The inner case is held off from the steam pipe, to make an air space, by means of short corrugated tin plate rings.

The tin plate case of No. 9 is made in one foot lengths, with two opposite longitudinal ribs projecting inwards. Each length is made in halves and the ribs are formed by turning in the edges so that they come double when the two halves are put together and fastened with solder. The cylinders are so joined end to end that their ribs lie in planes at right angles to each other. Both this covering and No. 37 are lacking in simplicity and ease of adjustment.

The air space of No. 19 is made in a ready way by winding around the pipe narrow strips of asbestos paper, some distance apart, before the covering is clamped on. In No. 12 the complex cylinder of hair and pasteboard is held off from the pipe by short, thick paper cylinders.

In No. 20, the air space was made in a cheap and easy way with

rings of plaster of Paris placed a foot apart, and a cylinder of straw board sprung on over them. This straw board had been shaped by rolling it in the machine with which tinkers form stove pipe, and was made large enough to have one edge lap over the other a little. The plaster rings were made in halves, with a groove around the outside, to receive the string with which they were tied together on the pipe. Such rings can be cast with little trouble, and they should be well dried before using. They could be made of porous terra cotta at trifling cost, and it would be better to fasten them on with small wire. The half rings in No. 22 were cut out of thin pine boards with a scroll saw, and the straw board was tacked to them; but pine rings shrink and become scorched, while those of plaster or burned clay are hard, incombustible, and poor conductors of heat. The case of No. 24 was made in the same way, but with an incomplete cylinder of straw board, so that there was left, along the whole length of the upper side, a narrow aperture through which the slag wool was crowded in. The long aperture was closed over with a somewhat wider strip of straw board, the whole being finally held together by winding twine around.

The rice chaff of No. 18, the sphagnum of No. 22, and the charcoal of No. 29 were put on with the help of a wire cage specially contrived for the purpose.

It requires some practice to put on paste coverings with a trowel, and it is by no means easy to get them uniform and round. With the exception of the fossil meal, the plastered coverings are worthless when they are taken off.

I have observed no chemical action by any of the coverings except such as contain plaster of Paris, which, while wet, rusts iron rapidly. The corrosion of pipe, which is said to have occurred sometimes with slag wool that had become damp, must have been caused by the sulphate of lime formed by the oxidation of a trace of sulphide of calcium in the slag.

Respecting durability, little can be learned by trials lasting only a few weeks. But it is well known that animal and vegetable substances undergo a change by long-continued heating, and this sometimes becomes obvious even after a few days' exposure. Wool, hair, cotton and paper in contact with a pipe at 150°C., soon turn brown and have their elasticity much impaired. To be sure, it is only a moderate thickness that becomes so affected, and samples of old coverings that

have been sent me show that it takes years to scorch any considerable portion of the whole depth.

Straw suffers farther out than the poorer conductors. Specimen No. 39, which was said to have been in use nine years, was still bright and straw-like outside, but the steam pressure had been under fifteen pounds. The straw alone in this sample weighed 4·2 ounces per foot, while the new straw of No. 28 weighed 10·6 ounces. If No. 28 really represents the original dimensions and character of No. 39, as it was intended to, the impairment of efficiency by the shrinkage bears a strikingly small proportion to the loss of weight.

The change of organic matters by a steam heat is too slow to produce any sensible odor, but if by any chance hair felt gets wet while on the pipe, it gives out an unpleasant smell for a long time. I have known instances in which this proved so great an annoyance that the covering had to be stripped off; and the possibility of such an occurrence is no slight objection to the use of hair in immediate contact with the hot pipe. The intervention of an air space offers a possible prevention of this trouble as well as of the crisping of the hair.

As to the chances for spontaneous combustion of any covering consisting of vegetable fibre, it is difficult to pronounce with certainty. There is a report in circulation that a certain paper covering has taken fire of itself; but I believe this is rather a matter of interested surmise than of positive proof. I put two pieces of the indicted covering on a pipe near the boiler, where the temperature was very high outside and at least 150°C. within the pipe—one of the pieces as it came from the maker, the other charged with cotton-seed oil (this oil readily induces the combustion of cotton waste), and yet both the paper tubes remained so exposed to heat for six months without showing the slightest inclination to take fire.

Of course, coverings made of organic substances become excessively dry and tinder-like when they are constantly exposed for a long time to a steam heat, and then they very readily catch fire when a spark or a flame touches them. Therefore, though there is little danger of fire from within, it is well to guard against fire from without. The impregnation of cloth wrappings with borax, tungstate of soda, or water-glass is calculated to lessen very much the danger from fire.

In connection with the testing of what were offered for fire-proof window shutters some years ago, I was led to believe that one of the best and cheapest non-conductors could be made of water-glass and

wood charcoal, since by charring, all gas-forming material is eliminated from the wood, and carbon does not oxidize rapidly when covered with the varnish-like and fusible silicate. It was this mixture that I tried in No. 29; but as there was no light pine charcoal at hand I was obliged, by want of time for making some, to take a rather too dense substitute. Still the result is encouraging, and I hope to follow up the matter farther, for this concreted uninflammable coal is capable of many useful applications.

The rice chaff in No. 18 was also mixed with enough water-glass to render it somewhat coherent when dry, and as the chaff is itself rather silicious we thus get a covering so charged with mineral matter as to be hard to set on fire, and at the same time quite light and efficient as a non-conductor. Doubtless, chopped straw might be used in the same way. But sawdust soaks up so much water-glass as to make a paste that dries too dense.

Coverings that contain flour or meal are liable to be troubled somewhat by mice. Even silicated rice chaff is not altogether proof against them. These animals also gnawed the interior of specimen No. 12.

When it is desirable to have a covering water-proof outside, this can be effected best by putting on a wrapper of sized cloth and applying to it one or two coats of oil paint. Of course, this should be done only after the covering has become perfectly dry. But trouble is sometimes caused from within, by leaking joints, and in such a case a water-proof coat only occasions a spreading of concealed mischief inside. On the other hand, a very porous coating allows the vaporized water to escape, and, if the leak is slight, no harm is done. It is well to use a pretty loose material for covering the joints, to separate those parts from the rest by impervious diaphragms of tin plate or plaster, and to make them so that they can be easily removed without disturbing the other portions.

The following table of specimens tried, Table I, is arranged in the order of their transmitting power as shown by the calorimetric method. The first column gives the source from which each of the samples was obtained, together with a concise description of the make up, beginning with the coating next the pipe. Those marked "J. M. O." were home productions.

The maximum diameter is given in the second column, few being quite cylindrical.

The weight in the third column includes the average of the whole

of the covering, but in many cases the essential part constitutes only a moderate portion of the whole weight. Fuller details of the structure are given in the second table.

The fourth column gives the highest temperature observed in the air chambers durings the trials. In one or two instances the covering was so irregular that the air chambers could not be made to fit closely enough for a fair trial, and so no figure is given.

The numbers in the fifth column show the condensation by each foot of the covered pipe in one hour. "Gross" signifies that the condensation by the fittings and extra pipe is not allowed for, and the figures given are, therefore, really from one-fourth to one-third too high. The method given above for eliminating this error was not invented till most of the trials had been made. In the trials made latterly the word "net" shows that the proper deduction has been made. It takes many days to get the data for the requisite correction, and it is hardly worth the while to spend the time for this, with many samples, till further careful experiments shall show whether the matter of mist really vitiates the results of the condensation method as much as we may suppose it can.

The sixth column shows how many heat units are actually transmitted in an hour by one foot in length of the pipe covering—that is, how many degrees centigrade one kilogram of water may be heated by it, or how many kilograms of water may be raised 1° C.

In the last column the same loss of heat is expressed in degrees Fahrenheit which one pound avoirdupois of water may be heated.

As all the samples beyond No. 30 allow more than twice as much heat to pass through as is transmitted by No. 1, it would seem that in No. 31 and all after it, there is much room for improvement.

The average of the 46 coverings—No. 50 being left out—is 24·623 kilogram-centigrade heat units transmitted.

The average weight is 49 ounces, or a little over three pounds per foot.

TABLE I.

	Diameter of Covering.	Weight per foot in oz. Av.	Maxim'm heat in air chambers.	Condensed 1 ft., 1 hour, in grams.	Kilo-cent'g Heat units 1 ft., 1 hour.	Pound-Fahr. Heat units, 1 ft., 1 hour.
	In.		Deg. C.		Deg.	Deg.
No. 1. From LOWELL FELTING MILL—I. Hair felt, with single cover of burlap	5⅝	21·4	53·98	40·67 gross.	12·842	50·966
No. 2. From LOWELL FELTING MILL—II. Hair felt, with single cover of burlap	4½	13·2	58·0		12·999	51·590
No. 3. CHALK & LAWTON, Pawtucket, R. I.—II. Slag wool, wooden cage, burlap, cotton cloth, double	8	117·8	39·5	43·00 gross.	14·465	57·408
No. 4. H. W. JOHNS' Non-Cond. Covering—II. Asbestos fibre, asbestos paper, hair felt, asbestos paper, hair felt, asbestos paper, canvas	5⅜	29·3	47·88		14·498	57·539
No. 5. GREENWOODS Co., New Hartford, Conn. Asbestos paper, hair felt, canvas	4½	17·3	61·8		15·074	59·705
No. 6. CHALMER SPENCE Co., New York—II. Asbestos paper, hair and pasteboard coiled together	4⅝	30·1	55·65		15·713	62·361
No. 7. ASBESTOS PACKING Co.—III. Asbestos paper, double, hair felt, paper, canvas	4½	19·9	51·61		15·761	62·551
No. 8. ASBESTOS PACKING Co.—II. Asbestos paper, hair felt, paper, canvas	5	18·4	53·46	41·00 gross.	16·078	63·809
No. 9. CHALMER SPENCE Co.—V. Air space, tin plate case, hair felt, canvas	4¾	20·8	57·0		17·122	67·952
No. 10. CHALMER SPENCE Co.—I. Asbestos paper, hair and pasteboard coiled together	4⅜	21·7	62·0	51·00 gross.	17·551	69·255
No. 11. H. W. JOHNS' Non-Cond Covering—VI. Asbestos paper, hair felt, paper, canvas	4	17·2	61·9		17·801	70·647
No. 12. CHALMER SPENCE Co.—IV. Air space, asbestos board, hair felt, asbestos paper, hair felt, pasteboard	6½	58·1	59·7		18·588	73·717
No. 13. H. W. JOHNS' Non-Cond. Covering—I. Asbestos paper, asbestos paste, hair felt, asbestos board, hair felt, asbestos board, canvas	7¼	105·3	48·22		19·291	76·385
No. 14. J. H. GRAHAM & SON, Boston—III. Clay, paper, hair felt, laths, plaster	5	52·9			19·423	77·085
No. 15. J. H. GRAHAM & SON—V. Asbestos paper, hair felt, paper, canvas	4½	16·1	65·0		19·632	77·913
No. 16. REED'S Covering—I. Paper cylinder, joint covered with paper	4⅜	30·5	61·0		19·670	78·064
No. 17. CHALMER SPENCE Co.—III. Asbestos paper, hair and asbestos paper coiled together	4⅝	30·3	53·5		20·129	79·886
No. 18. J. M. O. Silicated rice chaff, cotton cloth cover	4¾	22·7	60·0		20·203	80·181
No. 19. REED'S Covering—II. Air space, asbestos paper, paper cylinder	4¾	29·3			20·439	81·117

TABLE I—*Continued.*

		Diameter of Covering	Weight per foot in oz. Av.	Maxim'm heat in air chambers.	Condensed 1 ft., 1 hour, in grams.	Kilo-cent'g Heat units 1 ft., 1 hour.	Pound-Fahr. Heat Units, 1 ft., 1 hour.
		In.		Deg. C.		Deg.	Deg.
No. 20.	J. M. O. Air space, straw-board, hair felt, no cover	4¾	12·0			20·693	82·124
No. 21.	S. C. NIGHTINGALE & CHILDS—IV. Fossil meal and hair plastered on	4¾	60·7		58·00 gross.	21·151	83·940
No. 22.	J. M. O. Air space, straw-board, peat moss, cotton cloth	4¾	10·6			21·631	85·848
No. 23.	J. H. GRAHAM & SON—I. Air space, hair felt, laths, plaster	5⅜	63·1	51·4		21·820	86·596
No. 24.	J. M. O. Slag wool, straw-board	4¼	24·1			22·807	90·510
No. 25.	J. M. O. Slag wool, straw-board	4⅜	24·8		46·50 net.		
No. 26.	S. C. NIGHTINGALE & CHILDS—I. Fossil meal and hair plastered on	4¼	31·9	64·5		22·942	91·050
No. 27.	S. C. NIGHTINGALE & CHILDS—II. Fossil meal and hair plastered on	4⅛	26·9			23·462	93·113
No. 28.	W. E. PARKER, Pacific Mills—I. Rys straw rope wound around, cotton cloth 4 ple.	4½	20·2	64·8	55·00 gross.	24·424	96·933
No. 29.	J. M. O. Silicated hard wood, charcoal, cotton cloth cover	5	41·9		47·00 gross.	24·650	97·830
No. 30.	J. M. O. Carbon, plaster of Paris, flour and hair plastered on	4½	33·0			26·909	106·800
No. 31.	ASBESTOS PACKING CO.—IV. Asbestos paste, clay and flax, paper pulp, mortar	5½	100·1	63·0		27·411	108·78
No. 32.	J. M. O. Dry rice chaff, straw board	3¾	8·4			27·607	109·56
No. 33.	J. H. GRAHAM & SON—IV. Asbestos and clay, laths, paper, mortar	5	58·0	66·0		28·159	111·75
No. 34.	CHALMER SPENCE CO., "Patent Air Space." Half-inch air space, wire netting, asbestos paste	5	41·0	72·8	74·00 gross.	28·579	113·43
No. 35.	S. C. NIGHTINGALE & CHILDS—III. Fossil meal and hair	3¼	17·1			28·882	114·62
No. 36.	CHALMER SPENCE CO., "Solid Covering." Asbestos paste	4½	34·4	74·2	61·00 gross.	29·599	117·47
No. 37.	CHALK & LAWTON—II. Air space, tinplate case, asbestos paper, tinplate case	4	29·0	52·14		29·660	117·71
No. 38.	EUREKA COVERING CO., Fitchburg, Mass. Meal, clay and hair, meal, clay, sawdust, flax fibre	5¼	81·9	70·0	79·00 gross.	30·171	119·74
No. 39.	W. E. PARKER, Pacific Mills—II. Rye straw rope, cotton cloth 6 ple (after nine years' use)	4¼	9·8	70·8		30·286	120·20

TABLE I—*Continued.*

	Diameter of Covering	Weight per foot in oz. Av.	Maxim'm heat in air chambers.	Condensed 1 ft., 1 hour, in grams.	Kilo-cent'g Heat units 1 ft., 1 hour.	Pound-Fahr. Heat Units, 1 ft., 1 hour.
	In.		Deg. C.		Deg.	Deg.
No. 40. ASBESTOS PACKING Co.—I. Asbestos paper, plaster and flax fibre	5⅛	111·5	73·8		31·267	124·09
No. 41. J. H. GRAHAM & SON—II. Plaster paste	5	67·5	79·8		33·477	132·86
No. 42. SAMUEL TAYLOR'S Non-Cond. Composition. Clay and short fibrous matter	5¼	94·1	77·3		36·782	145·98
No. 43. H. W. JOHNS' Non-Cond. Covering—IV. Asbestos paper, asbestos paste	6¼	201·8	69·2		37·951	150·61
No. 44. J. M. O. Anthracite ashes, plaster of Paris, flour, hair	4¾	79·2			39·150	155·41
No. 45. H. W. JOHNS' Non-Cond. Covering—V. Asbestos paper, asbestos paste	6½	171·2	70·0		41·079	163·03
No. 46. H. W. JOHNS' Non-Cond. Covering—III. Asbestos paper, asbestos paste	5¼	99·8	77·8	87·00 gross.	43·097	171·04
No. 47. J. M. O. Mere air space	2⅛				49·241	195·42
No. 48. J. M. O. Mere air space	4¾				50·405	200·04
No. 49. FALL RIVER STEAM PIPE COVERING Co. Clay and refuse of vegetable fibre	4¼	65·2	91·8		51·727	205·29
No. 50. J. M. O. Asbestos paper wound round four times	2⅞				56·371	223·72
No. 51. J. M. O. Naked pipe	2½			181·00 net.	391·830	1555·10

TABLE II.

No. 1. Hair felt, 826 grams; Burlap and twine, 85 grams. Length 18 inches.

No. 2. Hair felt, 493 grams; burlap, 50 grams; twine, 17 grams. Length, 18 inches.

No. 3. Slag wool, 2 inches thick, 3860 grams; wooden slats, $\frac{3}{4}$ inch thick, and nails, 1815 grams; wooden rings at ends, $1\frac{1}{2}$ inches thick, 540 grams; tinplate rings between Wooden rings and pipe, 51 grams; burlap, 127 grams; cotton cloth two thicknesses, and paint, 270 grams; tacks, 13 grams. Length, 24 inches.

No. 4. Asbestos paper faced with loose asbestos fibre, $16\frac{1}{2} \times 25$ inches, 205 grams; $\frac{3}{4}$ inch hair felt, $18 \times 10\frac{1}{2}$ inches, 282 grams; twine, 3 grams; asbestos paper, $17\frac{1}{2} \times 18$ inches, 112 grams; $\frac{3}{4}$ inch hair felt, $17\frac{1}{2} \times 14$ inches, 407 grams; twine, asbestos paper, $17\frac{1}{2} \times 16$ inches, 133 grams; canvas, 19×18 inches, 80 grams. Length, $17\frac{1}{2}$ inches.

No. 5. Asbestos paper, 119 grams; twine, 4 grams; hair felt, 458 grams; canvas, 94 grams. Length, $16\frac{1}{2}$ inches.

No. 6. Hair and pasteboard, not easily separated. Whole weight, 1280 grams. Length, 18 inches.

No. 7. Asbestos paper doubled, 110 grams; hair felt, 486 grams; paper, 157 grams; canvas and string, 93 grams. Length, 18 inches.

No. 8. Asbestos paper, two thicknesses, 98 grams; hair felt, $1\frac{1}{4}$ inches thick, $16\frac{1}{2}$ inches thick, $16\frac{1}{2} \times 12$ inches, 456 grams; twine, 6 grams; paper, $17\frac{3}{4} \times 31\frac{1}{2}$ inches, 156 grams; canvas, 87 grams. Length, $17\frac{1}{2}$ inches.

No. 9. Tinplate case and ribs, 580 grams; 1 inch hair felt, 494 grams; canvas and twine, 94 grams. Length, 23 inches.

No. 10. Hair and pasteboard cemented together. Whole weight, 910 grams. Length, $17\frac{3}{4}$ inches.

No. 11. Asbestos paper, three thicknesses, 172 grams; twine, 6 grams; 1 inch hair felt, 552 grams; twine, 23 grams; paper, 123 grams; canvas, 81 grams. Length, $23\frac{1}{2}$ inches.

No. 12. End pieces of paper, 3 inches long, lined with asbestos paper, 575 grams; asbestos paper, hair felt and pasteboard cemented together, 1860 grams. Length, $17\frac{3}{4}$ inches.

No. 13. Asbestos paper, two thicknesses, 167 grams; asbestos paste, 1 inch thick, 2910 grams; $\frac{3}{4}$ inch hair felt, 385 grams; twine, 5 grams; asbestos board, 220 grams; $\frac{3}{4}$ inch hair felt, 505 grams; twine, 6 grams; asbestos board, 301 grams; canvas, 107 grams. Length, $18\frac{1}{2}$ inches.

No. 14. Clay, 760 grams; paper, 115 grams, hair felt, 280 grams; laths, 430 grams; iron wire and plaster, 2270 grams. Length, 29 inches.

No. 15. Asbestos paper, several thicknesses, 299 grams; hair felt, 425 grams; twine, 2 grams; paper, 198 grams; canvas, 137 grams. Length, 28 inches.

No. 16. Alike throughout, 1280 grams. Length, $17\frac{3}{4}$ inches.

No. 17. Hair and asbestos cemented together, 1290 grams. Length, 18 inches.

No. 18. Silicated rice chaff, 1060 grams; wooden rings and cloth wrapper, 120 grams. Length, 22 inches.

No. 19. Asbestos paper rings, paper tube, whole weight, 1230. Length, 17¾ inches.

No. 20. Wooden rings and straw board, 249 grams; hair felt and twine, 443 grams. Length, 24½ inches.

No. 21. Fossil meal and hair, alike throughout, 2940 grams. Length, 20½ inches.

No. 22. Wooden rings, 87 grams; straw board, 192 grams; tacks, 5 grams; outer rings of paper, 1½ inches wide, 113 grams; sphagnum, 174 grams; cloth, 40 grams. Length, 24½ inches.

No. 23. Two iron rings, 1 inch wide, and tacks, 440 grams; ¾ inch hair felt, 218 grams; laths, 351 grams; wire and plaster, 2350 grams. Length, 21½ inches.

No. 24. Gypsum rings, 256 grams; straw-board cover, 201 grams; slag wool filling, 940 grams. Length, 24½ inches.

No. 25. Plaster ends, 253 grams; straw-board, 175 grams; slag wool filling, 802 grams. Length, 21 inches.

No. 26. Hair and fossil meal, uniform throughout, 980 grams. Length, 13 inches.

No. 27. Fossil meal and hair, uniform throughout, 1270 grams. Length, 20 inches.

No. 28. Straw rope, 1 inch thick, 400 grams; cotton cloth, four thicknesses, 400 grams; iron rings at the ends, not included in the weight given in Table I. Length, 16 inches.

No. 29. Silicated charcoal, 1760 grams; wooden rings and cloth wrapper, 120 grams. Length, 19 inches.

No. 30. Paste of plaster, carbon, flour and hair, 1560 grams. Length, 20 inches.

No. 31. Asbestos paste, 820 grams; clay and fibre, 960 grams; paper pulp, 1560 grams; twine, 23 grams; mortar, 3260 grams. Length, 42 inches.

No. 32. Wooden rings, 74 grams; straw board, 166 grams; tacks, 5 grams; rice chaff filling, 240 grams. Length, 24½ inches.

No. 33. Asbestos and clay, 580 grams; wood and wire, 325 grams; paper, 332 grams; plastering, 2052 grams. Length, 24 inches.

No. 34. Wire netting and sheet iron props, 210 grams; asbestos paste, 1340 grams. Length, 16 inches.

No. 35. Fossil meal and hair, uniform throughout, 770 grams. Length, 19 inches.

No. 36. Asbestos paste, uniform throughout, 1300 grams. Length, 16 inches.

No. 37. Corrugated rings of tin plate, 97 grams; tin plate cylinder, 345 grains; asbestos paper, 204 grams; tin plate cylinder, 445 grams; tin plate ends, 30 grams. Length, 16¾ inches.

No. 38. Two kinds of paste not separated, 3290 grams. Length, 17 inches.

No, 39. Straw rope, 160 grams; six thicknesses cotton cloth, 212 grams; iron rings at ends not reckoned. Length, 16 inches.

No. 40. Asbestos paper, 179 grams; three coats plaster with fibre, 4430 grams. Length, 17½ inches.

No. 41. Paste, uniform throughout, 5740 grams. Length, 36 inches.

No. 42. Clay and fibre, uniform throughout, 3500 grams. Length, 15¾ inches.

No. 43. Asbestos paper and twine, 102 grams; asbestos paste, 8760 grams. Length, 18½ inches.

No. 44. Ashes, plaster, flour and hair, uniform throughout, 3740 grams. Length, 20 inches.

No. 45. Asbestos paper, 113 grams; asbestos paste, 7370 grams. Length, 18½ inches.

No. 46. Asbestos paper, asbestos paste together, 4320 grams. Length, 18½ inches.

No. 47. Clay and fibre, alike throughout, 2310 grams. Length, 15 inches.

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Chalk and Lawton, Nos. 3, 37.
Chalmer Spence Co., Nos. 6, 9, 10, 12, 17, 34, 36.
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Fall River Steam Covering Co., No. 49.
Fossil meal, Nos. 21, 26, 27, 35.
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Samuel Taylor's non-conducting composition, No. 42.

PRESSURE ATTAINABLE BY THE USE OF THE "DROP PRESS."

By Robert H. Thurston, Hoboken, N. J.

[Read before the American Society of Mechanical Engineers, November, 1883.]

The writer has recently taken occasion to determine the magnitude of the pressures attainable and not infrequently utilized in the use of the "drop press," now so extensively employed in the process of "drop forging" and in the manufacture of small parts of sewing machines, firearms and light machinery.

The opportunity was afforded to make this determination in the course of an investigation of the efficiency of drop presses lately made by the Mechanical Laboratory of the Stevens Institute of Technology. It was found that the most efficient presses experimented with had an "efficiency," as the term is technically used, of 90 per cent.—*i.e.*, the work done by the drop was 90 per cent. of that which was due to the weight falling through the measured height. The table given below is based upon the assumption that this efficiency can be reached, and exhibits the mean pressure attained when the piece attacked is crushed to the amount of $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$ inch respectively. The maximum pressures must exceed those given. The mean pressures are calculated by determining the amount of energy of the falling drop at the instant before stopping—*i.e.*, of the quantity of work done upon it by gravity and stored in it, and dividing that measure in foot-pounds by the distance through which the crushing of the "work" takes place. These figures are seen to be simply enormous, and the power of this form of press is evidently limited only by the rigidity of its parts and their strength.

The figures given for the pressures reached when the compression is $\frac{1}{16}$ inch can be obtained only when the anvil is so set and of such material that the yielding there occurring cannot absorb more than the allowed 10 per cent. of the total work of the falling mass. The same remark applies to the table generally, but the loss may always be expected to fall within the assumed figure for the smaller weights and lesser heights fallen through. If the machine is well built and the anvil and foundation are of ample size and rigidity for good work, it is not improbable that the higher figures can be readily obtained; provided also that proper precautions are taken in the setting of the press.

The *intensity* of pressure attainable is evidently determined by the

area of the surface exposed to the action of the drop, and this in turn determines the distance through which crushing may occur. The figures given in the table are total pressures, and the meam intensity of pressure corresponding to these amounts is to be obtained by dividing the total pressure as shown in the table by the area of section of the crushed piece, or by the mean area opposed to the crushing action during the operation. The proper comparison is that of the energy of the falling weight with the "resilience," elastic or total, or both, of the mass on the anvil or in the dies.

PRESSURES OF THE DROP-PRESS.—(EFFICIENCY 90 PER CENT).

Fall of drop in feet and inches.	Compression in inches.	Weights of Drop								
		Pounds. 50.	Pounds. 100.	Pounds. 200.	Pounds. 400.	Pounds. 600.	Pounds. 800.	Pounds. 1,000.	Pounds. 1,500.	Pounds. 2,000.
0′3″	1-16″	2,160	4,320	8,646	17,281	25,921	34,562	43,202	64,803	86,405
	⅛″	1,080	2,160	4,320	8,640	12,960	17,281	21,601	32,401	43,202
	¼″	540	1,080	2,160	4,320	6,480	8,640	10,800	16,200	21,601
0′6″	1-16″	4,320	8,640	17,281	34,562	51,843	69,124	86,505	129,607	172,811
	⅛″	2,160	4,320	8,640	17,281	25,921	34,562	43,202	64,803	86,405
	¼″	1,080	2,160	4,320	8,640	12,960	17,281	21,601	32,402	43,202
0′9″	1-16″	6,480	12,960	25,921	51,843	77,764	103,686	129,608	174,412	259,216
	⅛″	3,240	6,480	12,960	25,921	38,882	51,843	64,804	87,206	129,608
	¼″	1,620	3,240	6,480	12,960	19,441	25,921	32,402	43,603	64,804
1′0″	1-16″	8,640	17,281	34,562	69,124	103,687	138,249	172,811	259,216	345,622
	⅛″	4,320	8,640	17,281	34,562	51,843	69,124	86,405	129,608	172,811
	¼″	2,160	4,320	8,640	17,281	25,922	34,562	43,202	64,804	86,405
1′6″	1-16″	12,960	25,921	51,843	103,686	155,529	207,373	259,216	388,824	518,432
	⅛″	6,480	12,960	25,921	51,843	77,764	103,686	129,608	194,412	259,216
	¼″	3,240	6,480	12,960	25,921	38,882	51,843	64,804	97,206	129,608
2′0″	1-16″	17,281	34,562	69,124	138,249	207,373	276,498	345,622	518,433	691,244
	⅛″	8,640	17,281	34,562	69,124	103,686	138,249	172,811	259,216	345,622
	¼″	4,320	8,640	17,281	34,562	51,843	69,124	86,405	129,608	172,811
2′6″	1-16″	21,601	43,202	86,405	172,811	259,216	345,622	433,028	648,042	864,056
	⅛″	10,800	21,601	43,202	86,405	129,608	172,811	216,014	324,021	432,028
	¼″	5,400	10,800	21,601	43,202	64,804	86,405	108,007	162,010	216,014
3′0″	1-16″	.....	51,843	103,686	207,373	311,059	414,747	518,433	777,649	1,036,866
	⅛″	.....	25,921	51,843	103,686	155,529	207,373	259,216	388,824	518,433
	¼″	.....	12,960	25,921	51,843	77,764	103,686	129,608	194,412	259,216
3′6″	1-16″	.....	.....	120,967	241,935	362,902	483,871	604,838	916,257	1,209,677
	⅛″	.....	.....	60,483	120,967	181,951	241,935	302,419	458,128	604,838
	¼″	.....	.....	30,241	60,483	90,975	120,967	151,209	229,064	302,419
4′0″	1-16″	.....	.....	.....	276,498	414,747	552,996	691,244	1,036,866	1,382,488
	⅛″	.....	.....	.....	138,249	207,373	276,498	345,622	518,433	691,244
	¼″	.....	.....	.....	69,124	103,686	138,249	172,811	259,216	345,622
5′0″	1-16″	.....	.....	.....	.....	518,434	691,245	864,056	1,296,084	1,728,112
	⅛″	.....	.....	.....	.....	259,217	345,622	432,028	648,042	864,056
	¼″	.....	.....	.....	.....	129,609	172,811	216,014	324,021	432,028

The limit to the resistance of any mass on the anvil is found at the

pressure at which the metal will "flow" continuously. This pressure varies not only with the kind of metal, but also with every variation in the chemical composition, the physical structure or the form and method of support of the piece. For general use the value of this "modulus" may be taken at about the value of the shearing resistance of the material. For soft wrought iron, for example, it may be taken at about 50,000 pounds per square inch (3,515 kg. per sq. cm.) for moderately hard iron at a figure 20 per cent. higher, and for pure copper at about one-half the latter figure. There is, however, a great difference in the behavior of the two metals under pressure. The former has a distinct elastic limit in its original state which becomes "exalted," as was shown by the writer some ten years ago, when the piece is distorted, and becomes approximately equal to the maximum force, producing change of form, remaining permanently altered. The metal thus transformed does not yield subsequently to any less pressure. It will not flow under any pressure less than that which is required to produce distortion immediately upon its application. Copper, however, has no true and measurable elastic limit in its original condition as found in the market, and it does flow under the continued action of forces far less than those required to produce rapid and continuous distortion by steady pressure. A load which produces no visible effect when first applied will after a time be found to have caused a very decided, and often a very extensive, alteration of the form of the mass. This is also a now well-known property of some kinds of brass and of many other metals belonging to what the writer has called the tin class, to distinguish them from the metals of the iron and steel class, which do not exhibit this treacherous behavior. This difference is of some importance, not only as indicating the best method of working them, but also as showing that the first of these two classes is a safer class to deal with where the metal is to be used in the carrying of heavy and unintermitted stress than is the second class.

Another important distinction between these two classes is, as indicated by the results of investigations made by the writer, that the "iron class," which includes all the irons and all of the steels, offers more resistance as the rupturing action is slower, while the "tin class," which includes nearly all the other metals and very nearly all of the alloys that the writer has ever tested, yields the more readily the more slowly the distortion goes on. The second class is thus subject to that

singular kind of change of form under heavy, continuous stress which is illustrated in the movement of all viscous solids—ice, for example, as seen in its flow in the glacier. This, it seems probable, may often occur under pressures far within those which are required to cause change of form in the testing machine in the ordinary methods of test. Iron has been found by Vicat, and later by the writer, to exhibit some such a phenomenon, but only when the pressures are considerably above one-half those usually found for the moduli of rupture, and this action is only seen in serious degree when the iron has been annealed and thus softened. Common merchant iron, so far as the writer is aware, does not show any tendency to such slow and imperceptible yielding under moderate loads.

The bearing of these facts upon the value of the drop press as a means of working iron and other metals into shape is obvious. Change of form can begin only when the elastic limit of the material is passed, and flow can progress steadily and uninterruptedly only when the pressure applied is in excess of the resistance of the metal in question to flow. The soft metals which belong to the "tin class" are best attacked by processes which cause a comparatively slow motion of their particles in changing form; iron and steel, on the contrary, being less resistant at high than at low velocities of flow, are best wrought by methods which produce rapid distortion. Professor Kick, of Prague, has shown very plainly that this difference in the amount of work demanded by the soft metals under the two kinds of treatment may amount to a very important quantity. He finds that the distortion of bodies by the action of the hydraulic press and by the action of a hammer dealing a succession of blows to produce the same change of form consume power in the ratio, in some cases, of one to ten. It is thus evident that the hammer or the drop is to be used for those special cases in which the pressures desired can not be reached by ordinary methods, and that it is best adapted to the working of iron and steel. The hydraulic press and automatic machinery are to be preferred where they can be conveniently and cheaply used. For much of the work that is now done in our smaller kinds of manufacturing, the drop has been shown by experience to be the only machine which will give the required enormous pressures and do the work rapidly and cheaply.

The maximum area of surface exposed to pressure which will be allowable for any given amount of compression can be determined

approximately by dividing the total mean pressure due to the action of the drop with the given fall, and the proposed compression by the maximum resistance of the material. The maximum area which will permit any action upon the surface is to be ascertained by dividing the same maximum pressure due the fall of the drop by the elastic limit of the metal in compression.

The total work absorbed, or the resilience of the mass, up to the elastic limit is to be measured by multiplying the elastic resistance by one-half the precentage of compression which marks the elastic limit; the result measures the resilience in inch-pounds when the unit of measure is the inch, and in centimeter-kilograms when the units are metric. The total work done in any permanent change of shape is proportional to the volume affected and to the maximum resistance of the material to such deformation.

What figures shall be adopted for the resistance to be calculated upon in the production of flow in metals subjected to the action of the drop press is a question which the writer is unable to answer definitely. It would seem probable that the effect of the blow may be, in the case of cold metal, somewhat similar to that of cold-rolling, and, this being the case, the initial resistance to flow must be taken as at least 70,000 pounds per square inch (4,921 kg. per sq. cm.) and the resilience during flow at as high as 70,000 inch-pounds per cubic inch (4,921 kg. m., per cubic centimeter) for good common wrought iron. It may be safe to take the figure for hot iron, as usually wrought at less than one-half this amount. For copper the writer would, in the absence of exact data, take the work of deformation to be two-thirds that of iron for pieces of small section, and would expect a great increase of resistance with either metal when the surface acted upon by the drop becomes large in proportion to its thickness. Probably no very reliable figures can yet be given. Whatever the resistance may be, the drop will be very certain to overcome it, and the variation in its amount will simply determine how many blows must be struck to obtain a given amount of change of form.

Phosphorescent Paper.—The *Papier Zeitung* gives the following recipe for preparing a waterproof paper, which will shine in the dark: 10 parts water, 40 parts paper stock, 10 parts phosphorescent powder, 1 part gelatine, and 1 part bichromate of potash.—*Dingler's Journal*, November, 1882. C.

THE THEORY OF TURBINES.

[ABSTRACT.]

By ROBERT H. THURSTON.

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1. INTRODUCTION.—The theory of whirl as given in some standard works and text-books on hydraulic machines, is partly based upon an hypothesis which is only approximately correct for a single rare case, and which is widely inaccurate for all usual forms of this class of "prime movers." The hypothesis here referred to assumes that the total effort of centrifugal force, and the work done by or against this force, are precisely the same whether the mass of water is at rest relatively to the wheel, as in a Whitelaw turbine, revolving with the orifices closed, or in motion, traversing the passages of the wheel, as in ordinary work; it further assumes that this action is the same whatever the motion, as to direction and velocity, relatively to the wheel.

The falsity of this hypothesis is obvious when it is considered that the action of centrifugal force is determined, not simply by the motion of the wheel itself, as previously assumed, but by the absolute motion of the water passing through the wheel. In the design of the turbine, it is easy to produce an indefinite variety of paths—in space—for the water sweeping through the wheel, and yet to secure maximum efficiency. This path may be made nearly straight in some forms of turbines with guides, and thus centrifugal action may be prevented; or the path may be a spiral of any desired class—as, for example, in "Barker's mill" or Segner's wheel—and centrifugal force thus made a maximum and the work done by or against that force is also a maximum.

These two thus form the limits between which all ordinary cases fall. In very many outward-flow turbines, having narrow crowns, the path of the water, in space, is so nearly rectilinear that the centrifugal action may be neglected. In fact, the best Boyden and Francis wheels have been designed without reference to the accelerating action of this force;* the form of bucket is such as to give a rectilinear path

* Francis remarks: ". . . it is difficult to see how centrifugal force can operate in the important manner that is commonly assigned to it." Lowell Hydraulic Experiments, p. 42.

to the water, and the velocity and volume of discharge have been calculated as if no such acceleration occurs, and their high efficiency is a proof that such cases may be safely so treated. In inward-flow wheels, a class to which a very large proportion of the most successful wheels now constructed belong, this action is of importance.

Since the energy gained or expended by centrifugal action is neither added to nor subtracted from the lost energy of the wheel, the rate of discharge into the tail-race being constant, as it may always be made by properly adjusting the speed of rotation of the wheel, it is evident that the efficiency of the wheel cannot be affected by it, and that it simply determines a change of the speed which produces the best effect. Thus, for example, were it possible to make two "reaction wheels" of the Scotch type, in one of which this action should be felt and in the other not, the speed of highest efficiency of the former would be infinite, while that of the latter would be finite, and yet the efficiencies of both wheels might, according to pure theory, be maxima.

In the outward flow turbines, as actually constructed, this modification of speed is practically unobservable and the effect of centrifugal action on the maximum of efficiency is still less perceptible, although the path, in space, of the water crossing the wheel is not rectilinear, but considerably curved. This is, however, largely a matter of design, and the engineer may easily so form his wheel-buckets, within tolerably wide limits, as to obtain a considerable or an inconsiderable centrifugal action. As the form of the bucket is the line of relative motion of the water and wheel, he may adopt any path and any law of variation of absolute angular and radial motion that he may find convenient or that he may desire, and, constructing the relative motion so obtained, obtain a form of bucket which will give the proposed motion in space.

2. Centrifugal force, in turbines, has the effect of causing a change in the head acting in the wheel to produce outflow at the orifices on the delivery side of the wheel and thus of producing a difference in the amount of actual energy stored in the issuing stream. This change of head causes an increase of velocity in the water flowing through the wheel-passages of outward-flow wheels, a decrease in inward-flow, and no change in parallel-flow wheels; it thus is measured by a head which is deducted from the total head driving the first class and is added to that driving the second class of wheels, the final velocity being the same; or, the head-race level being the same, and

the orifices unchanged in area, the effect is to increase the head at the orifice, or to diminish it, as the case may be, and thus to cause acceleration or retardation of flow. This action has a useful regulating effect in the inward-flow wheel and a disturbing action in the outward-flow turbine.

3. The magnitude of the total effect varies with the extent to which the water partakes of the rotation of the wheel, being a maximum, as already stated, where they have the same angular motion, and becoming zero when the path of the fluid in space is made rectilinear; it may have any intermediate value.

As shown in all works on mechanics, the acceleration due to centrifugal force is

$$f = \frac{v^2}{r} = a^2 r \qquad (1.)$$

where v, r, and a are respectively the linear velocity, the radius, and the angular velocity of the particle in its orbit. This dynamic measure, f, of centrifugal force is so related to the static measure, F, of its effort and to the weight, W, that

$$\frac{F}{W} = \frac{f}{g};\ F = Mf = \frac{W}{g} a^2 r\ \therefore F = 2\,\frac{W}{r}\frac{v^2}{2g} = \frac{2}{r} Wh \qquad (2.)$$

when g and h are the acceleration of gravity and the height due the velocity, v. Then

$$F = W\frac{v^2}{rg} = Wr\frac{4\pi^2 r}{gt^2} = 1{\cdot}224\, W\frac{r}{t^2} = 0{\cdot}00034 N^2 Wr$$

if N = revolutions per minute, t = time of one revolution in seconds; this is a useful standard equation.

4. The work of centrifugal force is easily determined when the law of variation of v with r is known. Thus $F = \frac{W}{g} a^2 x$ and the work done by or against F in transit from one point to another along any line, having angular motion, a, is

$$U = \int F dx = W\frac{a^2}{g}\int_{x_1}^{x_2} x dx = W\frac{a^2}{2g}(x_2^2 - x_1^2) \qquad (3)$$

When $x = r$,

$$U = \frac{W}{2g}(v_2^2 - v_1^2) \qquad (4)$$

when v_1 and v_2 are the linear velocities, initial and final.

Again, when a body enters upon any path, in a revolving system, with an initial velocity, V_1, relative to that system, and leaves with a relative velocity, V_2, no other force acting upon it than the deviating centrifugal force, the change of energy will be due to the action of that force and will measure the work done by it. Then

$$W\frac{V_2^2 - V_1^2}{2g} = W\frac{v_2^2 - v_1^2}{2g};\quad V_2^2 - V_1^2 = v_2^2 - v_1^2.$$

$$V_2 = \sqrt{(v_2^2 - v_1^2 + V_1^2)} = \sqrt{[V_1^2 + a^2(r_2^2 - r_1^2)]} \qquad (5)$$

The energy gained is

$$U_2 - U_1 = W\frac{V_2^2 - V_1^2}{2g}$$

and the head, h_e, to which the change is due

$$h_e = \frac{V_2^2 - V_1^2}{2g} = \frac{a^2}{2g}(n^2 r_1^2 - r_1^2) = (n^2 - 1)\frac{a^2 r_1^2}{2g} \qquad (6)$$

when $n = \frac{r_2}{r_1}$.

5. First case.—The maximum possible work of centrifugal action in any form of turbine is thus found to be

$$U_e = W(n^2 - 1)\frac{a^2 r_1^2}{2g} = DQ\frac{a^2 r_1^2}{2g}(n^2 - 1) \qquad (7)$$

if D and Q are the specific heaviness and the volume of water flowing through the wheel per second.

The coefficient, $(n^2 - 1) = f(n)$, will be of frequent occurrence in later equations.

The head, $(n^2 - 1)\frac{a^2 r_1^2}{2g} = h_e$, accelerates outward and retards inward flow, since $n^2 - 1$ is positive for outward and negative for inward-flow wheels, and the head at the penstock must be

$$h = h_1 - h_e \text{ and } h_1 = h + h_e \qquad (8)$$

if h_1 is the head due the velocity of outflow through the exit orifices when h is the head due the energy at entrance.

6. A second case in which the linear velocity of rotation, v, diminishes uniformly, as the water traverses the wheel, is that probably most usually illustrated in turbines. When the wheel is driven at the speed of maximum efficiency, this velocity becomes zero at the exit and the motion of the issuing current is simply radial. Then

$$v = \frac{r_2 - r}{r_2 - r_1} v_1;\ v^2 = \left(\frac{r_2 - r}{r_2 - r_1}\right)^2 v_1^2 = \left[\frac{n - \frac{r}{r_1}}{n - 1}\right]^2 v_1^2;$$

and $$DQ h_e = \frac{DQ}{g}\int_{r_1}^{nr_1} \frac{v^2}{r}\, dr = \frac{2DQ}{(n-1)^2}\frac{v_1^2}{2g}\int_{r_1}^{nr_1}\left(n - \frac{r}{r_1}\right)^2 \frac{dr}{r};$$

$$= \frac{2DQ}{(n-1)^2}\frac{v_1^2}{2g}[2n^2 \log_e n - 4n(n-1) + n^2 - 1]; \quad (9)$$

$$h_e = \frac{2v_1^2}{2g(n-1)^2}[2n^2 \log_e n - 4n(n-1) + n^2 - 1] = \frac{v_1^2}{2g} f(n) \quad (10)$$

Here, as before, the coefficient of the quantity $\frac{v_1^2}{2g}$, which measures the head due the initial velocity of whirl v_1 is simply a function of n.

7. A third case is that in which the *energy*, instead of the velocity of rotation, of the particle is given a uniform increment or decrement, *i. e.*, $d\left(\frac{v_1^2}{2g}\right)$ = constant instead of dv = constant. This case is less frequently met with than the last, but is probably not infrequently approximated in practice. Then

$$v^2 = \frac{r_2 - r}{r_2 - r_1} v_1^2 = \frac{n - \frac{r}{r_1}}{n - 1} v_1^2;$$

$$DQh_e = \frac{2DQ}{n-1}\frac{v_1^2}{2g}\int_{r_1}^{nr_1}\left(n - \frac{r}{r_1}\right)\frac{dr}{r};$$

$$= 2DQ\,\frac{v_1^2}{2g}\left(\frac{n}{n-1}\log_e n - 1\right) \quad (11)$$

and $$f(n) = 2\left(\frac{n}{n-1}\log_e n - 1\right) \quad (12)$$

This adjustment of velocities produces considerably greater values of $f(n)$ than the preceding, and is, therefore, probably more desirable for inward-flow wheels.

8. Other methods of variation of v may be adopted by the hydraulic engineer, as, for example, $v = v_1$ = constant, when flow varies,

$$DQh_e = 2DQ\,\frac{v_1^2}{2g}\int_{r_1}^{nr_1}\frac{dr}{r} = DQ\frac{v_1^2}{2g}.\ 2\log_e n \quad (13)$$

and $$f(n) = 2\log_e n. \quad (14)$$

8. Numerical values of $N = f(n)$ are given in the following tables for each of the above cases:

TABLE I.

Values of $f(n)$ in Equation 7.

$v \propto r$.

n	$f(n)$	n	$f(n)$
0·1	−0·99	1·1	+ 0·21
0·2	−0·96	1·2	+ 0·44
0·3	−0·91	1·3	+ 0·69
0·4	−0·86	1·4	+ 0·98
0·5	−0·75	1·5	+ 1·25
0·6	−0·64	1·6	+ 1·56
0·7	−0·51	1·7	+ 1·89
0·8	−0·36	1·8	+ 2·24
0·9	−0·19	1·9	+ 2·61
1·0	−0·00	2·0	+ 3·00

TABLE II.

Values of $\frac{1}{2} N$ in Equation 9.

dv = constant; $v \propto (r_2 - r)$

n	$f(n)$	n	$f(n)$
0·1	−0·834632	1·1	+ 0·065068
0·2	−0·701180	1·2	+ 0·127148
0·3	−0·585133	1·3	+ 0·186570
0·4	−0·481147	1·4	+ 0·243569
0·5	−0·386294	1·5	+ 0·298374
0·6	−0·298715	1·6	+ 0·351157
0·7	−0·217129	1·7	+ 0·402104
0·8	−0·140578	1·8	+ 0·451338
0·9	−0·068417	1·9	+ 0·498993
1·0	−0·000000	2·0	+0·545175

TABLE III.

Values of N in Equation 11.

$d(v^2) = \text{constant}$; $v \propto (r_2 - r)^{\frac{1}{2}}$.

n	$f(n)$	n	$f(n)$
0·1	−1·488314	1·1	+ 0·096824
0·2	−1·195281	1·2	+ 0·187858
0·3	−0·969802	1·3	+ 0·273824
0·4	−0·778279	1·4	+ 0·355305
0·5	−0·613706	1·5	+ 0·432791
0·6	−0·467523	1·6	+ 0·506686
0·7	−0·335553	1·7	+ 0·517837
0·8	−0.214850	1·8	+ 0·645040
0·9	−0·103509	1·9	+ 0·710049
1·0	−0·000000	2·0	+ 0·772589

TABLE IV.

Values of N in Equation 13.

$v = v^1$ constant.

n	$f(n)$	n	$f(n)$
0·1	−4·6052	1·1	+ 0·1906
0·2	−3·2189	1·2	+ 0·3646
0·3	−2·4180	1·3	+ 0·5241
0·4	−1·8326	1·4	+ 0·6629
0·5	−1·3863	1·5	+ 0·8109
0·6	−1·0217	1·6	+ 0·9400
0·7	−0·7134	1·7	+ 1·0612
0·8	−0·5463	1·8	+ 1·1055
0·9	−0·2107	1·9	+ 1·2837
1·0	−0·0000	2·0	+ 1·3863

9. A Turbine consists of a pair of cylindrical rings or flat annular bands revolving about an axis, usually horizontal but often vertical, and connected by curved buckets or vanes. It differs from the older forms of wheels in the fact that the water passes *through* the wheel,

the buckets having two openings, the one for entrance and the other for exit, while in the other forms of water wheel, the buckets have but a single opening, the water entering and leaving by the same orifice. The turbine is also distinguished by the method of transfer of energy from water to wheel. In the old forms of wheel, the fluid acts by weight, as in overshot and breast-wheels, or by impulse and later reversion with reaction, as in the Poncelet form of undershot; while, in turbines, the transfer is never by weight and is usually principally due to impulse and reaction without reversal of relative motion.

10. The Action of the Turbine is substantially the same in all its forms. A current of water flowing from under a certain head, with a velocity which in some cases is that due the total head, as in the "turbines of free deviation," and sometimes to a part of that head only, as in pressure turbines, is given a certain lateral direction or whirl, such that the energy of direct flow becomes but a small fraction of the total energy of the fall, and this whirl is then taken up and its energy given out upon the wheel which only permits its discharge, if working correctly, when all energy of whirl has been applied to drive the wheel and when the energy of direct flow has been made a minimum.

The resultant motion of water and wheel is that of the current on the wheel, and the absolute motion of the stream may be made whatever the engineer may desire, within certain limits, by making the path on the wheel such as, at the best speed of the turbine, shall produce that motion. The character of this motion, while the available energy of the fall is being taken up by the wheel, is usually determined either by custom or by the individual preference of the designer. It is properly determined by the character of the wheel which is to be designed. Generally, in outward-flow wheels, the path of the water in space, while traversing the wheel-buckets, should be nearer rectilinear than in inward flow wheels in order that the action of centrifugal force produced by the whirl should disturb the former as little, and assist in regulating the latter as much as possible. The paths of the current in space and on the wheel may be obtained either by the generally rough empirical methods which are given in the older treatises on turbines and are usually practised in the drawing office, by more exact graphical construction, or by precise construction from the equations of the curves representing those paths as given later in this paper.

11. Friction in the guide passages and bucket-channels causes a loss of a notable part of the energy of the fall.

For any given style of turbine, its amount may be readily estimated and as nearly correctly as is practically important. Calling the whole head H, and the head lost by friction h_f, the remaining usefully applicable part of the head will be

$$h_1 = H - h_f \qquad (15)$$

In the following treatment, it will be assumed that the friction-waste is thus accounted for and the theory of the turbine will be developed without regard to this loss, considering the head acting on the turbine to be simply h_1.

12. Ineffective guidance is sometimes a cause of serious loss of energy. This occurs when the passages are so large in cross section, so short and so sharply curved, that the stream, instead of following closely and in full volume, the line of the bucket or guide-curve, flows more nearly straight across from entrance to exit, in a smaller stream, and leaves the sharp turns in the curve filled with a mass of eddying water, which does not move through the channel with the full velocity demanded in efficient working. This is an effect of sharply curved passages in wheels having an insufficient number of buckets or guides. The best wheels have a sufficient number of guides and buckets to prevent this loss, while they have no more than is really necessary, and are therefore not subject to excessive loss by friction. It will be here assumed that this loss may be neglected.

13. Final radial or axial flow produces a loss which is, to a certain extent, unavoidable, as the discharged water must be thrown into the tail-race, with enough velocity to carry it clear of the wheel, and must have so much velocity in the wheel, in direct flow, that the desired power may be obtained, and the necessary volume of water worked off to produce that power, without adopting too large a wheel; excessive size not only causes increase of cost of wheel and attachments, but also an increase of loss by friction of mechanism. The magnitude of this necessary waste is determined by the designer, by reference to the results of experience, or by his judgment after studying the proposed location and the conditions under which the wheel is to be operated; it varies usually from two to ten per cent. of the total energy of fall, according to size of wheel and to circumstances surrounding it.

Final whirl is usually intended to be either zero or so nearly zero that this waste of energy may be neglected.

14. Regulation is generally secured in turbines by the use of an adjustable "gate," or equivalent, which, usually under the control of some form of powerful governor, adjusts the flow of water to the demand of the load.

In nearly all cases, the partial closing of the gate results in a partial contraction of the stream entering the wheel, or the guide curves, and a consequent loss of head, which is often a serious tax upon the efficiency of the wheel. In the turbine of usual form, in which the current enters the wheel under pressure, and in which the bucket channels must be kept full to give maximum efficiency, the gradual closing of the regulator causes a gradual reduction of pressure in the wheel, and thus, at some point, converts it into an impulse and reaction wheel without pressure, and the velocity of exit from the guides at the same time becomes more nearly that due to the total head, h_1. This change in the method of operation of the wheel leads to a waste of energy, also, as it compels the working of the wheel at a wrong speed and under conditions for which it was not designed. An advantage which often partly compensates this defect, however, is that the range of regulator motion through which the usually experienced variation of power demanded carries the wheel, is somewhat extended and regulation is thus made easier; this occurs by the increasing velocity of flow V_1, as the pressure in the wheel is reduced while the regulator is closing, and *vice versa;* the tendency is thus to regulate, by decreasing the volume of flow rather than the working head, h_1.

In the theory of the operation and the efficiency of the turbine, it is assumed that the wheel is working at full gate. Where a large but uniform amount of power is demanded, the great loss of efficiency thus met with in some classes of wheels can be reduced by putting in two or more wheels, one only of which is regulated, the other or others being worked at full gate, and thrown off or on as may be necessary, one by one.

15. The Pure Theory of Turbines is very simple, and the principles of their construction are easily deduced therefrom. Neglecting the action, for the present, of centrifugal force and the losses by friction, the action of the regulator and other causes of waste which are more or less avoidable, it is easy to derive expressions for maximum efficiency, and from them to deduce principles guiding the engineer in their design and construction.

In all cases the efficiency is

$$E = DQ(h_1 - h_2) \div DQh_1 = \frac{h_1 - h_2}{h_1}. \qquad (16)$$

where

D = the heaviness of water;
Q = the volume of water flowing per second;
h_1 = the head in the supply chamber;
h_2 = the total loss of head.

In DQh_2 may be included all losses of energy, whether by leakage, friction, or final flow. It is evident that it is a matter of indifference, which form or type of wheel is adopted, so far as its efficiency is concerned, provided that these losses are reduced to the same minimum. All wheels of the same type will, theoretically, have the same efficiency, if designed with the same angle of discharge, β, and for the same velocity of final outflow.

Since the form of wheel is, to a certain extent, a matter of indifference, and an infinite variety of wheels may in theory be made to give the same efficiency, it is evident that it will be necessary, in order to ascertain the proportions of parts, to study the special types of wheel proposed to be used in order to ascertain the values of h_1 the total head driving the wheel, and especially of h_2, the loss of head, and thus to determine for each case the principles involved in the correct method of working for high efficiency.

The value of the maximum efficiency of certain types of wheel can be written out at once in certain cases. Of the total energy reaching the wheel, when revolving at that speed which reduces final whirl to zero, none is lost, except that of final direct flow. If β is the exit angle of the wheel bucket, reckoned between the tangent and the line of flow, the velocity of final flow is, in the "turbine of Whitelaw," $V \sin. \beta$; the lost energy is $DQV^2 \sin.^2 \beta \div 2g$; the energy of the fall is $\frac{DQV^2}{2g}$, and the efficiency is

$$E = DQ\left(\frac{V^2 - V^2 \sin.^2 \beta}{V^2}\right) = 1 - \sin.^2 \beta = \cos.^2 \beta \qquad (17)$$

For certain cases in which the head giving whirl is divided, as in the parallel flow wheel, the one half producing the flow from the guides, the other half causing acceleration in the wheel and final relative whirl, the efficiency is obviously

$$E = \frac{DQ(h_1 - h_2)}{\frac{DQ}{2}(h_1 - h_2) + \frac{DQ}{2}(h_1 - h_2)\sec.^2\beta} = \frac{2}{1 + \sec.^2\beta}$$

$$= \frac{2}{2 + \tan.^2\beta}. \qquad (18)$$

It is seen that when a wheel is turning at the best speed, the efficiency depends solely upon the magnitude of the angle of discharge, β, and that the lost energy is simply that of final direct flow, and that the efficiency approaches unity as β approaches zero. It is further seen that, as the speed can always be adjusted as to prevent loss of energy by final whirl, the study of types and forms is principally important as affording a means of ascertaining the method of division of head and the probably best velocity of rotation.

The following treatment is, for the reasons above indicated, directed to the cases of simple types of wheel and to a general discussion relating to the case usually met with in works on this subject.

16. The turbine of uniform direct flow is one to which analysis can be readily applied, and one from the theory of which the most general and instructive conclusions can be deduced. In this wheel, that component of the motion which takes the water into and through the wheel is uniform and equal to the velocity of final direct flow, and the whirl which constitutes the other component is usully varied, as the stream traverses the wheel, according to a very simple law. This uniformity of direct flow is secured in the parallel-flow wheel by making the wheel of equal diameters from receiving to discharging side, and in other wheels by making the depth between crowns vary inversely as the radius, if we neglect the thickness of the buckets, which, however, must be allowed for in designing.

It follows that, in this wheel, if

n = the ratio $\frac{r_2}{r_1}$ of the radii,
α = the terminal angle between the guides and tangent,
β = the angle of discharge, as above,
u = velocity of direct flow,

Since $Q = Au$ = constant and u = constant, tan. $\alpha = n$ tan. β; for the velocity of relative whirl, v_2, at β must be equal to nv_1, n times the whirl at exit from the guides, v_1, and the areas of passages normal to the whirl are inversely as these velocities of whirl, provided that the

speed of wheel at the receiving side is equal to the whirl of the entering water. Then

$$v_1 = u \div \tan.\, \alpha\,;\ v_2 = u \div \tan.\, \beta \tag{19}$$

$$v_2 = nv_1 = \frac{u}{\tan.\beta} = \frac{nu}{\tan.\alpha}$$

and, as stated above,

$$\tan.\, \alpha = n \tan.\, \beta \tag{20}$$

The velocities of the wheel, at the inner and the outer periphery, are

$$w_1 = ar_1\,;\ w_2 = ar_2 = nar_1 \tag{21}$$

where

w_1 = velocity of whirl of receiving side of wheel,
w_2 = velocity of whirl of discharging side of wheel,
a = angular velocity of the wheel,
r_1, r_2 = the radii.

Evidently, when working properly,

$$v_1 = ar_1\,;\ v_2 = nar_1 = ar_2 \tag{22}$$

In this wheel, so adjusted, the motion of each particle is uniform along a radial line, which line rotates about the centre of the wheel at such a rate that the linear velocity of whirl is uniformly diminished from a maximum at entrance, and becomes zero at its exit from the wheel.

17. The theory of the turbine of uniform direct flow is best constructed by considering the distribution of energy usefully and wastefully, and deducing a value for the expression*

$$E = \frac{h_1 - h_2}{h_1}$$

The total energy expended is that due to the head, h_1; it is obtained thus (centrifugal action being at present neglected):

(*a*) Energy of initial whirl, $DQ\,\frac{v_1^2}{2g}$; head, $\frac{v_1^2}{2g} = h'$;

(*b*) Energy of initial flow, $DQ\,\frac{u^2}{2g}$; head, $\frac{u^2}{2g} = h''$;

(*c*) Energy of reversed whirl in the wheel, $DQ\,\frac{v_2^2}{2g}$; head, $\frac{v_2^2}{2g} = h'''$.

* This form of wheel is that studied by Rankine (Prime Movers, Part II, Chap. VI).

The last item is the energy gained in the wheel buckets, due to the difference of pressure at the entrance and exit sides, when the wheel is at the best speed. When not at this speed, this energy becomes

$$(c') \quad DQh''' = \frac{DQ}{2g}\left[v_2^2 - (v_1 - ar_1)^2\right]$$
$$= \frac{DQ}{2g}\left[n^2 v_1^2 - (v_1 - ar_1)^2\right]$$

The energy, $\frac{DQ}{2g}(v_1 - ar_1)^2$ must be reckoned with other lost work.

The total energy expended is, for the last, or general, case.

$$(A) \quad DQh_1 = \frac{DQ}{2g}\left(h' + h'' + h'''\right)$$
$$= \frac{DQ}{2g}\left[n^2 v_1^2 (1 + \tan.^2 \beta) + 2a r_1 v_1 - a^2 r_1^2\right] \qquad (23)$$

since $u^2 = n^2 v_1^2 \tan.^2 \beta$.

The effective energy is obtained by deducting from the above the lost energy: this consists of

(*e*) Energy of final flow, $\frac{DQ}{2g}u^2 = \frac{DQ}{2g}n^2 v_1^2 \tan.^2 \beta$

(*f*) Energy of final whirl, $\frac{DQ}{2g}(v_2 - n a r_1)^2 = \frac{DQ}{2g}[n(v_1 - ar_1)]^2$

and the total waste is

$$(B) \quad DQh_2 = \frac{DQ}{2g}[n^2 v_1^2 (1 + \tan.^2 \beta) - 2an^2 r_1 v_1 + n^2 a^2 r_1^2] \qquad (24)$$

and when the energy due the quantity $v_1 - ar_1$ is lost, we also have a waste,

(*g*) Energy wasted at entrance, $\frac{DQ}{2g}(v_1 - ar_1)^2$

The total effective energy is

$$(A) - (B) = \frac{DQ}{2g}(n^2 + 1)(2ar_1 v_1 - a^2 r_1^2) \qquad (25)$$

The efficiency is, for the case taken,

$$E = \frac{(A) - B)}{(A)} = \frac{(n^2 + 1)(2ar_1 v_1 - a^2 r_1^2)}{n^2 v_1^2 (1 + \tan.^2 \beta) + 2ar_1 v_1 - a_2 r_1^2} \qquad (26)$$

The maximum efficiency is evidently obtained when the wheel is at

its normal speed and the loss by whirl is a minimum; and this, as is seen by inspection, occurs when

$$v_1 = ar_1 \tag{27}$$

When $v_1 = ar_1$; $v_2 = nv_1 = nar_1 = nr_2$, and

$$E_{max.} = \frac{n^2 + 1}{n^2 \sec.^2 \beta + 1} = \frac{n^2 + 1}{n^2(1 + \tan.^2 \beta) + 1} \tag{28}$$

For the parallel flow turbine, $n = 1$, and the general equation for E becomes

$$E = \frac{4ar_1v_1 - 2a^2v_1^2}{v_1^2 \sec.^2 \beta + 2ar_1v_1 - a^2r_1^2} \tag{29}$$

$$E_{max.} = \frac{2}{\sec.^2 \beta + 1} = \frac{2}{2 + \tan.^2 \beta} \tag{30}$$

The limit of maxima is approached as β approximates to zero; this limit is unity for all cases.

The case of the turbine of parallel flow above, is an example of the equal division of head, $h_v = \frac{v_1^2}{2g} + \frac{v_2^2}{2g} = 2\frac{v_1^2}{2g}$, since $v_1 = v_2$; and this form of turbine, with uniform axial flow, other things equal, is therefore probably that least subject to loss of energy by friction.

18. Numerical Values of the maximum efficiency of turbines of uniform direct flow are as follows, for the most usual cases in which, for the outward, the inward, and the parallel flow wheels, respectively, $\frac{r_2}{r_1}$ is taken equal to $n = 1{\cdot}41$, $n = 0{\cdot}50$; $n = 1$.

EFFICIENCY OF TURBINES.

Outward Flow, $n = 1{\cdot}41$.		Inward Flow, $n = 0{\cdot}50$.		Parallel Flow, $n = 1$.	
β	$E_{max.}$	β	$E_{max.}$	β	$E_{max.}$
10°	0·980	10°	0·994	10°	0·985
15°	0·955	15°	0·986	15°	0·968
20°	0·918	20°	0·975	20°	0·939
25°	0·872	25°	0·958	25°	0·901
30°	0·819	30°	0·866	30°	0·856

For the "Reaction Wheel" of the usual form, in which β can be made o without causing difficulty either of construction or operation, we have

$$E_{\max.} = 1.$$

Comparing the above figures it is seen that for equal values of β, the inward flow wheel is most efficient; but it is not possible to adopt as small values of β in this wheel as in the outward flow; in practical work it may usually be assumed that $n \tan. \beta = a$ may be made the same for all classes of wheel, although this value may be made slightly smaller in the inward flow wheel which has a slight advantage in this respect. The values below may be taken as usual for good wheels; they

$n = 1{\cdot}41$	$n = 1$	$n = 0{\cdot}50$
$a = 14° - 20°$	$a = 14° - 20°$	$a = 14° - 20°$
$\beta = 10° - 14°$	$\beta = 14° - 20°$	$\beta = 20° - 30°$
$E = 0{\cdot}980 - 0{\cdot}985$	$E = 0{\cdot}968 - 0{\cdot}975$	$E = 0{\cdot}93 - 0{\cdot}87$

are often considerably greater. The apparent defect of efficiency in the inward flow wheel is compensated by its smaller size and less friction, and often, by the use of a "draught tube."

19. The total head acting on any wheel in which the whirl v_1 and the velocity of rotation, a_1 are fixed, has been found to be

$$h_1 = (n^2 v_1^2 \sec.^2 \beta + 2ar_1 v_1 - a^2 r^2) \div 2g. \tag{31}$$

The expression, when v_1 is constant and efficiency a maximum, gives $ar_1 = v_1$ and

$$2gh_{1\ \min.} = n^2 v_1^2 \sec.^2 \beta + a^2 r_1^2 = (n^2 \sec.^2 \beta + 1). \tag{32}$$

When $a = o$ the wheel becoming fixed,

$$2gh_1 = n^2 v_1^2 \sec.^2 \beta = v_2^2 \sec.^2 \beta. \tag{33}$$

and the whole energy of fall is wasted, the water issuing from the wheel with the velocity due the whole head, less that lost by friction, while the effort exerted on the wheel becomes a maximum.

20. The ratio, $\frac{ar_1}{\sqrt{2gh_1}}$, of the velocity, ar_1, of the receiving side of the wheel to the velocity due the head, $\sqrt{2gh_1}$, is, at maximum efficiency,

$$Z_1 = \frac{ar_1}{\sqrt{2gh_1}} = \frac{1}{\sqrt{(n^2 \sec.^2 \beta + 1)}} \tag{34}$$

which becomes, for parallel flow wheels,

$$Z_1 = \frac{1}{\sqrt{(\sec.^2 \beta + 1)}} = \frac{1}{\sqrt{(2 + \tan.^2 \beta)}} \tag{35}$$

and hence, in the parallel flow wheel, in which $n = 1_1$

$$*E_{max.} = \frac{2}{\sqrt{(2 + \tan.^2 \beta)}} = 2z_1^2 \tag{36}$$

For $\beta = 30° = a$, Morin finds, by test of this kind of wheel, $z_1 = 0.65$; the above expression gives $z_1 = 0{\cdot}66$.

The value of z', the ratio of the velocity of the delivery side of the wheel to that due the head is determined by the design ot the wheel; in these wheels, $z' = n\, z_1$, and

$$Z' = \frac{n\, a\, r}{\sqrt{2gh}} = \frac{n}{\sqrt{n^2 \sec.^2 \beta + 1}} = \frac{n}{\sqrt{n^2 + n^2 \tan.^2 \beta + 1}} \tag{37}$$

which, when $n = 1$, gives

$$Z' = \frac{a\, r_2}{\sqrt{2gh}} = \frac{1}{\sqrt{2 + \tan^2 \beta}} \tag{38}$$

as before, and

$$E_{max.} = \frac{n^2 + 1}{n^2 \sec^2 \beta + 1} = \frac{n^2 + 1}{n^2} Z_1^2 \tag{39}$$

$$Z' = \frac{n\sqrt{E}}{\sqrt{n^2 + 1}} \tag{40}$$

This result is only correct for the class of wheels here treated of, in which the direct flow is uniform and $\tan a = n \tan \beta$.

21. The division of the total head into the two parts producing, respectively, velocity in the guides and pressure and acceleration in the wheel may now be easily determined for best effect.

Neglecting the energy of direct flow, which is fixed by the designer in accordance with known conditions of working, the remaining energy of the fall takes effect in producing whirl in the guides and a reversed whirl in the wheel; the total is

* Rankine finds this result accordant with Morin's experiment; but he deduces this expression for "all turbines with guide-blades" (Prime Movers, pp. 195, 196), which is manifestly incorrect.

$$U_w = DQ\frac{(n^2+1)\,v_1^2}{2g} \tag{41}$$

Of this, one part, $h_a = DQ\frac{v_1^2}{2g}$ is that of initial whirl and the other part, $h_b = DQ\frac{n^2 v_1^2}{2g}$, is that of reversed relative whirl in the wheel; they thus have the relation,

$$\frac{1}{n^2+1} : \frac{n^2}{n^2+1} = 1 : n^2. \tag{42}$$

22. The "turbine of free deviation," or turbine without pressure, is another typical case which, if radial flow be uniform, can be treated by an equally simple method. In this turbine the water escapes from the guides, with the full velocity due the head, into a wheel in which there is no pressure in the buckets. In this case the total energy of the fall is developed as kinetic energy at entrance into the wheel, and is there gradually converted into useful work, the relative whirl becoming a maximum, and the absolute whirl a minimum, at exit from the buckets.

Then we have

Total Energy Expended:

Initial whirl, $DQ\frac{v_1^2}{2g}$.

Initial flow, $DQ\frac{u^2}{2g} = DQ\frac{v_1^2 \tan.^2 a}{2g}$.

(*A*) Total, $DQ\frac{v_1^2 \sec.^2 a}{2g}$. (43)

(*B*) *Energy Wasted:*

Final flow, $DQ\frac{v_1^2}{2g}\tan.^2 a$ (44)

Final whirl, *O*.

Effective Energy: $(A)-(B) = \frac{DQ}{2g}v_1^2$ (45)

Efficiency: $E_{max.} = \frac{(A)-(B)}{(A)} = \frac{1}{\sec.^2 a} = \cos.^2 a$ (46)

which approaches unity as a approaches 0.

At the speed of maximum efficiency, when final whirl is o,

$$ar_2 = nar_1 = v_1 - ar_1,$$

since the relative motion, $v_1 - ar_1$, along the bucket, remains unchanged and the only force acting upon the stream is a deviating force. Also, neglecting direct flow and centrifugal action, as before,

$$v_1 = (n+1)\,ar_1;\ ar_1 = \frac{v_2}{n} = \frac{v_1}{n+1} = w_1;$$

$$z^1 = \frac{v_2}{v_1} = \frac{n}{n+1}, \text{ nearly.} \tag{47}$$

when $n = 1$,

$$w_2 = ar_2 = v_2 = \tfrac{1}{2}v_1 = \tfrac{1}{2}\sqrt{2gh_1}, \text{ nearly.} \tag{48}$$

$$Z^1 = \frac{v_2}{\sqrt{2gh_1}} = \tfrac{1}{2} \tag{49}$$

In these, as in all wheels, the receiving edge of the bucket should make with the tangent to the wheel the angle

$$\delta = \frac{v_1 - w_1}{u} = \frac{nv_1}{u(n+1)}; \tag{50}$$

The angle of discharge, β, is so made that direct flow shall be uniform. It is not true that, for this wheel, n tan. β = tan. α, since the whirl of the wheel, w_1, is not equal to that of the water, v_1; but, for all these wheels,

$$v_2 \text{ tan. } \beta = v_1 \text{ tan. } \alpha;\ \text{tan. } \beta = \frac{v_1}{v_2} \text{ tan. } \alpha \tag{51}$$

23. The general theory of these turbines is easily constructed when the form of wheel is determined, and its elements can be expressed algebraically. Thus, let the velocities of whirl have any relation, *e. g.*, such that

$$v_2 = mnv_1; \tag{52}$$

In this case, a wheel of uniform direct flow will have such a speed that

$$w_1 = ar_1 = mv_1;\ w_2 = ar_2 = nar_1 = mnv_1 = v_2 \tag{53}$$

and the angle β must be of such magnitude that

$$\text{tan. } \alpha = mn \text{ tan. } \beta \tag{54}$$

and the angle δ such that

$$\text{tan. } \delta = \frac{v_1 - w_1}{u} = \frac{v_1(1-m)}{u} \tag{55}$$

Then it follows that the

Total Energy Expended is

Initial whirl, $DQ\,\frac{v_1^2}{2g}$;

Initial flow, $DQ\,\frac{v_1^2 \tan.^2 \alpha}{2g} = \frac{v_1^2 m^2 n^2 \tan.^2 \beta}{2g}$

Gained in the wheel, $DQ\,\frac{n^2 m^2 v_1^2 - (v_1 - ar_1)^2}{2g}$

$$(A)\ \textit{Total},\ DQh_1 = \frac{DQ}{2g}\,(n^2 m^2 v_1^2 \sec.^2 \beta + 2ar_1 v_1 - a^2 r_1^2) \qquad (56)$$

Energy Wasted:

Final flow, $DQ\,\frac{m^2 n^2 v_1^2 \tan.^2 \beta}{2g}$;

Final whirl, $DQ\,\frac{(mnv_1 - nar_1)^2}{2g}$;

$$(B)\ \textit{Total},\ DQh_2 = \frac{DQ}{2g}\,(m^2 n^2 v_1^2 \sec.^2 \beta - 2amn^2 r_1 v_1 + n^2 a^2 r_1^2) \qquad (57)$$

Efficiency:

$$E = \frac{(A) - (B)}{(A)} = \frac{h_1 - h_2}{h_1};$$

$$= \frac{2ar_1 v_1 - a^2 r_1^2 + 2ar_1 mn^2 v_1 - n^2 a^2 r_1^2}{m^2 n^2 v_1^2 \sec.^2 \beta + 2ar_1 v_1 - a^2 r_1^2} \qquad (58)$$

When $m = 1$, this expression reads

$$E = \frac{2ar_1 v_1 - ar_1^2 + 2an^2 r_1 v_1 - n^2 a^2 r_1^2}{n^2 v_1^2 \sec.^2 \beta + 2ar_1 v_1 - a^2 r_1^2} \qquad (59)$$

For best work, $mv_1 = ar_1$; tan. $\alpha = mn$ tan. β, and

$$E_{max.} = \frac{2mv_1^2 - m^2 v_1^2 + m^2 n^2 v_1^2}{m^2 n^2 v_1^2 \sec.^2 \beta + 2mv_1^2 - m^2 v_1^2} \qquad (60)$$

and, when $m = 1$ and tan. $\alpha = n$ tan. β,

$$E_{max.} = \frac{v_1^2 + n^2 v_1^2}{n^2 v_1^2 \sec.^2 \beta + v_1^2} = \frac{n^2 + 1}{n^2 \sec.^2 \beta + 1}; \qquad (61)$$

as already deduced for the previously discussed form of pressure turbine, centrifugal action neglected.

(To be continued.)

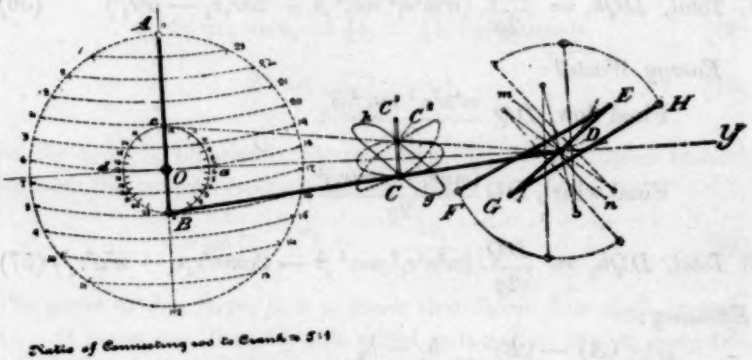
A NEW VALVE MOTION.

By CARL ANGSTROM, Worcester, Mass.

[Read before the American Society of Mechanical Engineers, November, 1883.]

This valve motion belongs to the same category as those of Brown, Marshall and Joy, and known by the name of "radial" valve motions.*

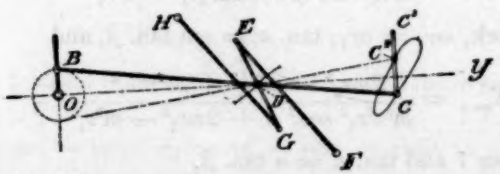
FIG. 1 *a*.



Ratio of Connecting-rod to Crank = 5:1

In a radial valve motion, the motion is generally accomplished by an arm, two points of which move in different curves. One point moves in a closed curve, such as a circle or an ellipse, this motion being derived from an eccentric, crank or from the connecting-rod. The other point again moves either in an open or a closed curve, and this motion is accomplished either by levers or slides, or both combined.

FIG. 1 *b*.



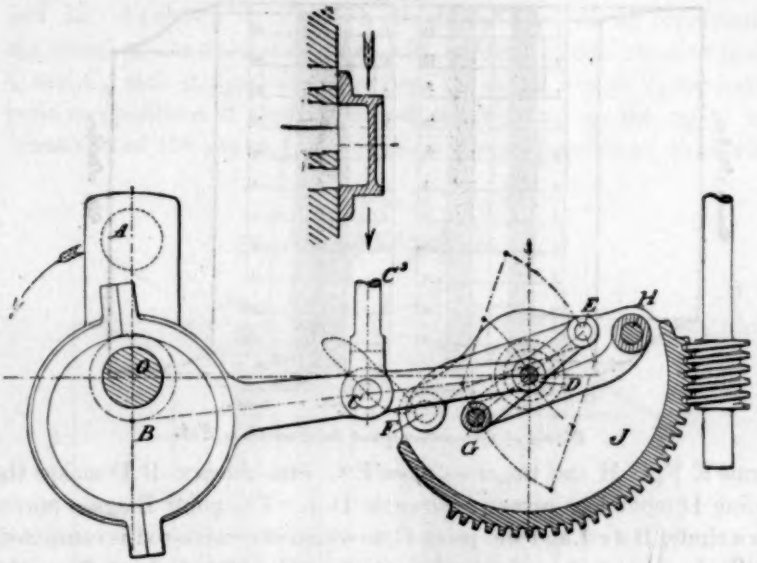
In the valve motion to be described the difference from those previously mentioned consists chiefly in the mechanism for giving motion to the last mentioned point of the valve actuating arm.

The outlines of the valve motion are shown in Fig. 1 *a*, in which O is

* "On Radial Valve Gears," by R. H. Graham. *The Engineer* (London), February 23, 1883.

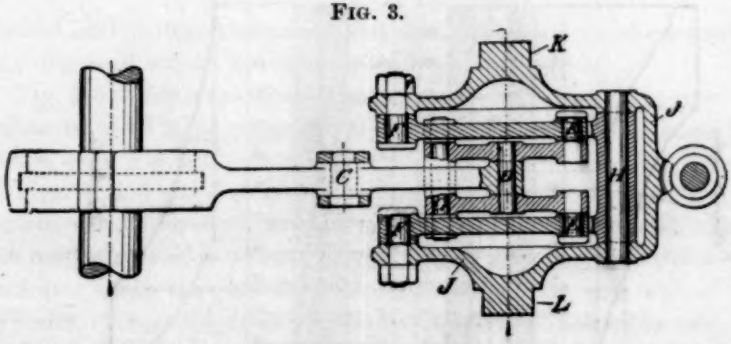
the centre of the main shaft, O A the crank, and O B the eccentric radius. The valve-rod C C^3 is attached to the arm B D at the point

FIG. 2.



C. The arm B D is connected at D by means of a cross piece E G to the two radial arms E F and G H. These radial arms are pivoted at E and H to a frame, J (see Figs. 2 and 3), this frame being free to turn on trunnions K and L, the center line of these trunnions being

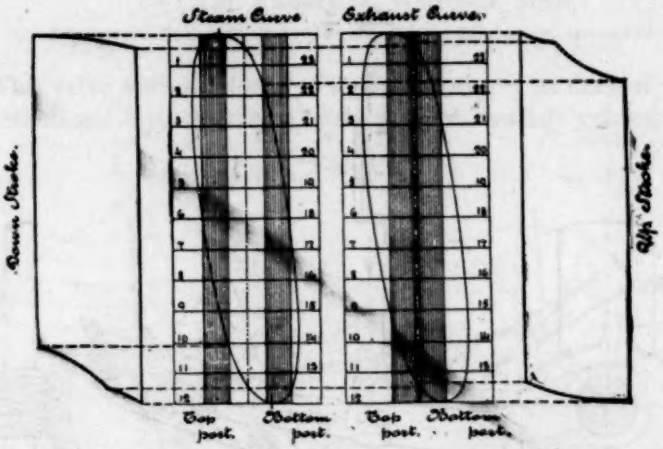
FIG. 3.



coincident with the point D on the rod B D at the end positions A and A^2 of the stroke A A^2 of the crank. The combination of the radial

FIG. 4.

Forward Motion.



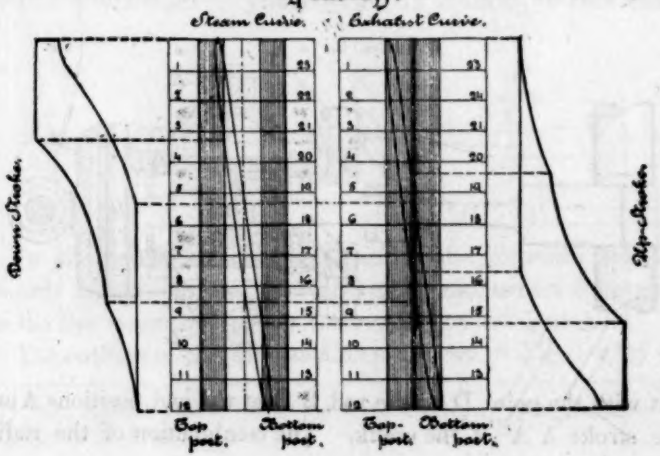
Ratio of Connecting rod to Crank = 5:1.

arms E F, G H and the cross piece E G with the arm B D makes the point D move in a reversed curve, *m* D *n*. The point B again moves in a circle, B *a c d*, and the point C, to which the valve-rod is connected, will thus have the combined movement C *g* C^2 *h* derived from the

FIG. 5.

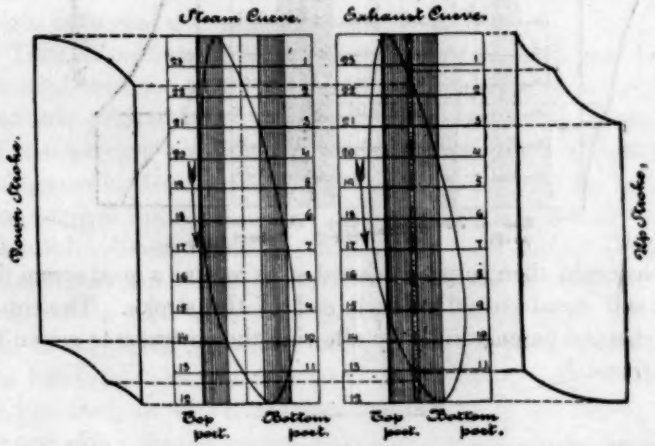
Forward Motion.

¼ Cut-off.



circle and curve motions. The degree of expansion and the reversing of the motion is accomplished by changing the angularity of the reversed curve *m* D *n* with reference to the line O Y. This change in angularity is done by simply turning the frame J on the trunnions K and L. As shown in Fig. 1 *a*, all the different curves representing the travel of the valve-rod pin C will intersect at two common points C and C_2, each at equal distances from the center line O Y, the corresponding positions of the piston and crank being at the upper and lower end of the stroke. The valve is proportioned so as to give the

FIG. 6.



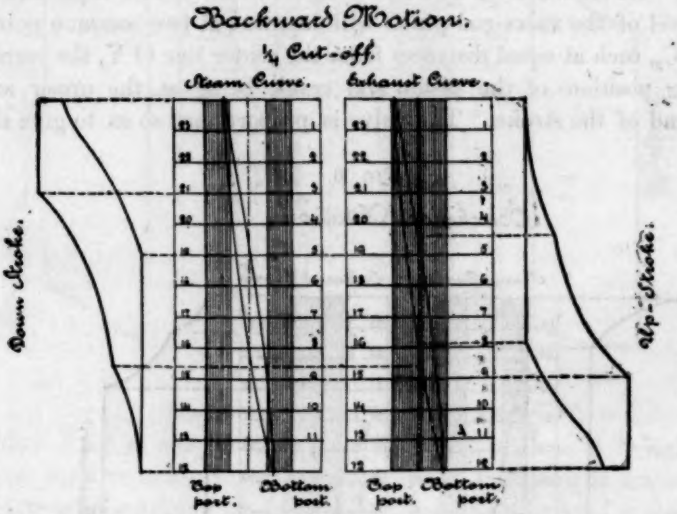
desired lead at these two points, and this lead then remains constant at any degree of cut-off at either forward or back motion.

Fig. 1 *b* shows a modified arrangement of this same valve gear, the valve-rod C C^3 being connected to the end of the rod B C, instead of inside, as in Fig. 1 *a*.

Figs. 4, 5, 6 and 7 illustrate the motion curves for full gear and for quarter cut-off for both forward and back motions. On each side of the motion curves, as shown in the figures, are diagrams similar to indicator cards, showing the steam distribution for each end of the cylinder. These diagrams are simply intended to assist in locating the various points on the motion curves. The curves for forward motion, Figs. 4 and 5, indicate an exceedingly quick opening or steam admis-

sion, while the closing or cut-off is more like a common link motion. It is thought that this valve motion can be used with advantage on engines running chiefly in one direction. The pendulum links and

FIG. 7.



connections could then be proportioned so as to give a good steam distribution and equal cut-off at each end of the stroke. The cut-off could be changed automatically by allowing the governor to act on the movable frame J.

Sounds Produced by the Wind.—Eolian harps and telegraph wires furnish familiar examples of musical vibrations which are produced by the action of the wind. The statue of Memnon and the monument near Karnac, which was described by Jollois and Devillers, emit musical sounds which have been variously explained. In the Sinaitic range there is a cone of sandy rocks, called the Gebel-Nakus. When a traveller attempts in fine weather to scale this miniature peak, he hears a sound like that of distant bells. When there is no wind and the sand is damp with dew the sound is not heard. The phenomenon is attributed to the friction of the siliceous sand on the declivities of the cone. The atmospheric vibration which is thus started is supposed to be intensified by cavities, which serve as sounding boxes, or resonators.—*Chron. Industr.*, March 25, 1883. C.

A SIMPLE AND SENSITIVE THERMOSTAT FOR INCUBATION AND ARTIFICIAL DIGESTION EXPERIMENTS.

By N. A. Randolph, M. D.

Of the many devices employed to maintain a constant temperature in water-baths or air-chambers the great majority are either expensive, bulky or unresponsive to slight thermic changes. The instrument about to be described presents no claim to novelty, except in the method in which alcohol is employed to increase its sensitiveness, but it occupies very little space, and can be made by any one, at an expense so slight as to render it available to every student.

Take an ordinary 6 inch by 1 inch test-tube, and pour in sufficient distilled mercury to fill the bottom of the tube to a height of one and one quarter inch. Fill the tube to two inches above the level of the mercury with rectified alcohol; force down a tight-fitting flat rubber cork, having one central perforation, until its lower surface just touches the alcohol, care being taken that no air bubbles are included. Then introduce through the hole in the cork a narrow tube, flared funnel shape, nearly half an inch in width at its upper end. This tube should fit very closely to the cork, and its lower end should reach to within an eighth of an inch of the bottom of the test-tube. Another flat and closely fitting rubber cork should be provided, in which are two holes, one in the centre, the other to one side. In the central hole is introduced a tube, the lower end of which is somewhat drawn out, so as to easily enter the enlargement at the top of the first tube. On one side of the second central tube, and about three-fourths of an inch from its narrowed end, a minute hole should be filed or blown of a diameter just sufficient to permit the passage of enough gas to keep a flame alive; the second (lateral) hole in the upper cork is fitted with a plain short tube, which is connected with the gas supply, the top of the central tube being connected with the burner warming the water-bath or other vessel.

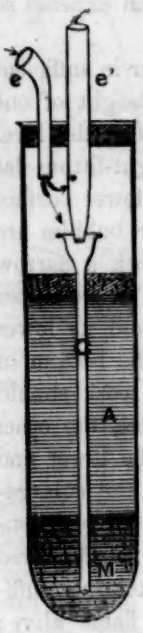
The completed apparatus is shown in section in the cut below, in which M represents the mercury, A the alcohol, C the funnel-tube projecting through the two liquids, e the gas admission tube, and e'

the gas exit tube provided with the small opening referred to, to keep the flame from being entirely extinguished.

The thermostat being placed in the same vessel with the material requiring a constant temperature, all the gas supplying the flame beneath the vessel is passed through the instrument and its volume modified as follows:

Upon any increase of temperature the alcohol can expand only downward, pushing the mercury up the lower central tube until it seals the lower end of the upper central tube, through which by far the major part of the gas (which enters by the lateral tube) escapes.

The flame being now reduced, any fall in temperature in the medium surrounding the thermostat and the material under observation will be followed by a descent of the mercury in the lower central tube, with a consequent unsealing of the main exit of the gas supplying the flame.



The instrument may be adjusted to maintain any temperature within certain limits by moving the upper central tube up or down, as the case requires. In the first adjustment a thermometer is necessary, but after the precise height to which the mercury rises at the required degree of heat is determined, the lower end of the upper central tube may be fixed at that point, and no further adjustment will be required for some time.

Should the minor gas exit (whose office is to permit the passage of just enough gas to preserve a mere point of flame) prove too large, the defect is easily remedied by pushing into the tube a small piece of paper, so bent as to accurately fit the interior of the tube, until the passage of gas through the minute hole is retarded to the proper degree.

A good glass-blower can make this instrument in one solid piece, in which case the adjustment (after the introduction of the alcohol) must be made by the addition or withdrawal through a capillary tube of minute globules of mercury.

In any case, the instrument must always be kept in an upright position.

Biological Laboratory of the University of Pennsylvania,
November 1, 1883.

Relations of Fluidity to Galvanic Conductivity.—Carl Stephen gives the following equation; $k = \frac{w K H}{w' \eta}$; in which K represents the conductivity of a water solution of the same temperature and percentage as an alcoholic solution with which it is compared; H and η, the internal frictions of the water and of the alcoholic fluid, for the same temperature; w and w', the percentages of water in the alcoholic solution and in a mixture of alcohol and water of minimum fluidity. He gives the following conclusions: 1. The frictional coefficient of many mixtures of water and alcohol, as well as the galvanic conductivity of diluted solutions of various salts, can be readily estimated. 2. The conductivity of diluted alcoholic solutions increases more slowly, when the amount of salt is increased, than that of water solutions. 3. The temperature coefficients of the conductivity of diluted solutions correspond very nearly to those of the fluidity of the solvent. 4. The conductivity of the alcohol-and-water solutions may be deduced from that of the corresponding water solutions, by a factor which depends only upon the solvent, and is the same for different salts. 5. If the proportion of alcohol is not greater than that of water the conductivity is very nearly proportional to the fluidity of the solvent.—*Ann. der Phys. und Chem.*, October 15, 1882. C.

Constitution of Comets.—No less than seven comets have been observed during the past year, one of which was photographed by Janssen in France, Common in England, and Draper in New York. Huggins states that carbon, hydrogen, and nitrogen are undoubtedly found in the substance of comets, and oxygen also is probably present. The chemical composition of twenty comets which have been studied appears to be essentially the same. There are often certain secondary modifications, which show that the predominant conditions are not rigorously uniform, and that they may vary from day to day in each comet. The temperature, the density, the amount of gaseous matter emitted by the nucleus, undergo continual variations. It is probable that the spectrum of hydrocarbon is complicated by traces of the spectra of compounds of oxygen and carbon. Meteorites are probably of the same nature as comets, and gases can be extracted from them in such quantities as to be exhibited before an audience. In 1867, Professor Odling, when lecturing upon the researches of Graham, lighted the lecture-room with gas that a meteorite had brought from the realms

of space. The meteorite was chiefly iron, and contained nearly three times its volume of gas, of which 85 per cent. was hydrogen, 5 per cent. carbonic oxide, and 10 per cent. nitrogen. Professor A. W. Wright found in a stony meteorite, gases which occupied a volume two and a half times as great as that of the meteorite, or twenty times as great as that of the iron which was dispersed in its mass. The gases were the same, but in different proportions. The idea that the light of comets and the phenomena of their tails are produced by electricity appears to be spreading. Zöllner, especially, has endeavored to show that the known laws of electricity are altogether sufficient to explain cometary phenomena. It has been commonly supposed that the bright lines in cometary spectra indicate heated luminous gases. Professor Wright and Johnstone Stoney think that the decomposed vapor is opaque, as compared with the special rays which appear like bright lines, and that the brightness is due to the reflection of the sun's rays from the vapor. Stoney regards the phenomenon as one of phosphorescence.—*Ann. de Chim. et de Phys.*, November, 1882. C.

Recent Progress of Electrical Science.—During the last four years one hundred and twenty-five patents have been taken out in England for dynamo-electric machines, and one hundred and seventy for electric lamps. The great financial disturbance in France interrupted the extension of electric lighting, and du Moncel laments the comparative indifference of the French inventors. The question of economy is still a doubtful one, but the practical question of satisfactory electric illumination has been thoroughly solved. The complete success of electric lighting on shipboard would naturally lead us to look for its application to railroad trains, but although many experiments have been made in England, France, and Italy, the system has not yet been adopted upon any line. The transport of energy by electricity has been utilized in some establishments, but there are no indications of its general introduction.—*La Lumière Electrique*, January 26, 1883. C.

Dynamogen.—M. Pétry has devised the following process for manufacturing an explosive paper, which he calls dynamogen. He puts upon the fire an enamelled iron pot containing 150 grammes of pure water, in which he dissolves 17 grammes of yellow prussiate of potash, and when it boils he adds 17 grammes of charcoal, stirring the

mixture well together. Allowing the whole to cool somewhat, he adds, successively, 35 grammes of potash, 70 grammes of chlorate of potash, and 10 grammes of starch triturated in 50 grammes of water. The whole is stirred, so as to constitute a very thin paste, which is spread with a brush over ordinary filtering paper. The paper is dried upon a moderately heated plate, and the other side is varnished in like manner. After three coats have been laid upon each side the paper is dried. It can be cut without danger and made into cartridges.—*Chron. Industr.*, January 1, 1883. C.

Invasion of England by a Subterranean Tunnel.—The opposition of the English Government to the construction of a tunnel under the English Channel has awakened great surprise. The French people can hardly believe that a great nation like England can allow itself to be guided by puerile fears. Some of their journals have reproduced an engraving, which was first published in 1803, and which shows that the idea of invading England by a tunnel had been formed at the very beginning of the century, at a time when Bonaparte had just visited the camp at Boulogne, and had monopolized all the vessels on which he could lay his hands, in order to carry out his famous project of a descent upon England. The engraving represents the channel as filled with ships-of-war and gunboats, the air with balloons freighted with soldiers, and large kites with gunners fastened to their tails, the fortresses on each side of the channel, and cavalry, infantry, and artillery marching through the tunnel. Although the engraving was probably intended as a burlesque, it seems no more absurd than the fears which threaten to prevent the execution of the tunnel, which was planned in 1875 and recommended by an Anglo-French commission in 1876.—*La Nature*, No. 497. C.

Protection against Rust.—Dr. Beckers has invented a preservative against rust, which is sold under the name of oil of caoutchouc, and which is said to have been introduced into general use by the German army. It is a varnish, prepared by mechanical means which have hitherto been kept secret, but which result in so intimate a mixture of the oil and caoutchouc that the latter preserves all its elasticity, and communicates it also to the oil. When rubbed by a flannel upon a metallic surface it dries slowly, forming a perfectly elastic, adhesive pellicle, which protects the metal from atmospheric influences.—*La Papeterie; Chron. Industr.*, No. 50. C.

Electric Omnibus.—The electrical storage company at Millwall, London, has constructed an electric omnibus, which moves with a velocity of six miles an hour. A number of accumulators, weighing 80 pounds each, and capable of driving the tramcar for seven hours, are placed under the seats and the current is communicated by insulated wires to a Siemens dynamo, which acts as motor. The electricity which is furnished by the accumulators, serves not only to drive the carriage but also to give it light.—*Lumière Electrique*, April 7, 1883. C.

Metallic Veins.—Dieulafait affirms that in a metallic vein there are always three constituents; the metallic substance, quartz, and sulphate of baryta. He has found, in many of the deep channels which are worn by glaciers, crystallized quartz, which must have been formed in the quaternary period, under conditions of pressure and temperature nearly identical with the present. He also finds, in examining 900 specimens of primordial rocks, that there is not one however small, which does not give appreciable quantities of sulphate of baryta, as well as of metals, diffused through the mass; he has thus recognized the presence of copper, lead zinc, manganese, and even vanadium, a metal which has been considered very rare. By observations in salt marshes and in the Caspian sea it has been found, that when fishes come into concentrated sea-water they die and fall to the bottom, where they decompose and produce sulphuretted-hydrogen which precipitates metals in the form of sulphurets; afterwards, the concentration still going on, the sulphate of lime is precipitated in its turn and covers the metalliferous layer, as in the Mansfield bed. Hence Dieulafait concludes that metalliferous layers, veins, pockets or ores, may be produced by mutual chemical actions, under present atmospheric conditions.—*Chron. Industr.*, March 25, 1883. C.

Transfer of Energy by Electricity.—In discussing Tresca's experiments at the Northern Railway station, the president of the Society of Civil Engineers remarked upon their great value. Even if a quarter of the original energy could be transmitted, there would be many cases in which a force could be transported to a distance, which it would be impossible to produce at the place where it is used. M. Chrétien, thought that the delivery would vary largely under varying conditions. He claimed personally, to have transmitted 60 per cent. in some cases, and even more.—*Chron. Industr.*, March 25, 1883. C.

CORRESPONDENCE.

Committee on Publication of the Journal of the Franklin Institute.

GENTLEMEN:—I have the honor to submit for publication the following new proposition on the attraction any solid body exerts at the level of a liquid mass surrounding it.

Prop. Let a liquid mass be in equilibrium around any solid body, whatever, the level of such liquid will be a surface of equal attraction.

In fact, the equilibrium being established, let us imagine an outer stratum of liquid of equal and very small thickness to become solid like a shell, without changing its density; and at different points of such shell let us drill equal holes and replace in them the same discs we have removed just as if they were pistons. It is evident that by the principle of equal transmission of pressure in hydraulics, and the condition of equilibrium, such discs must have all the same weight. Hence, the surface of level of the liquid must be a surface of equal attraction.

Corollary. If the disturbances caused by centrifugal force and luni-solar attraction on our planet be neglected, the level of the sea will be a surface of equal attraction.

L. D'AURIA.

PHILADELPHIA, Nov. 14, 1883.

Book Notices.

FRENCH FOREST ORDINANCE OF 1669. Compiled and translated by John Croumbie Brown, LL.D. Edinburgh: Oliver & Boyd, 1883.

It appears, from an examination of this work, that the famous Forest Ordinance promulgated by Louis XIV, King of France and Navarre, and since known as the French Forest Ordinance of 1669, forms the basis of all existing laws relating to the subject of forestry. It is, therefore, of much historical interest, aside from scientific bearings, and it is somewhat surprising to learn from Professor Brown that the text of this ordinance appears for the first time in the English language in his work.

It contains much that is curious and interesting, and to those who are specially devoted to the subject of forest preservation and cultivation—which is rapidly becoming an important one in the United

States—it will doubtless be highly appreciated. The author is a devoted student of the science of forestry, and his present translation and compilation will prove a most desirable contribution to the bibliography of the subject in the English tongue. W.

THE BREWER, DISTILLER AND WINE MANUFACTURER. Edited by John Gardner, F.C.S. Illustrated. Philadelphia: P. Blakiston, Son & Co., 1883. 12mo, pp. 278.

The volume here noticed is represented to be the first of a series of "Technological Handbooks," prepared with a view of conveying in condensed form as much practical information as possible, so that those desirous of informing themselves concerning the practical details of any one of the technological arts may find therein everything that is essential. The design is a good one, and there is need of a series of the kind named, if edited by competent specialists.

The present work forms a very creditable beginning of the series. It is quite comprehensive and, so far as we have been able to examine it, accurate. It will be found useful for reference by the manufacturer, and particularly valuable by the novice wishing to familiarize himself with the principles and methods involved in manufacturing fermented and distilled liquors, and alcoholic compounds generally.

The publisher announces that this volume will be followed by one devoted to bleaching, dyeing, etc. W.

THE ELEMENTS OF CHEMISTRY, for the Use of Schools, Academies and Colleges. By Edwin J. Houston, A. M., etc. Philadelphia: Eldredge & Brother, 1883.

There is room for a well-digested, systematic, elementary work upon chemistry, elucidating plainly the views respecting the nature of chemical force, the facts respecting gaseous combinations by volume, the theoretical ideas of the quantivalence of the elements and its influence on molecular structure, the theory of substitution, and other facts and theories, the general appreciation and acceptance of which have revolutionized both the nomenclature and the methods of teaching the science.

This need the author has succeeded very well in filling, and the present work may be safely recommended to teachers of chemistry as perhaps more clearly and concisely presenting the most recent developments of the science than any other elementary text-book extant.

The author has been exceptionally successful as a maker of text-books, as the popularity of his several works on Physical Geography and Natural Philosophy attests, and for this work he is especially well qualified by the gift of a happy faculty of clear and concise expression, in addition to which, his long experience as an instructor has enabled him to thoroughly understand the requirements of both teachers and pupils.

The present volume is fully illustrated, neatly printed on good paper, and substantially bound. It will, doubtless, take its place with the other works of this author, as a favorite text-book. W.

MANUAL OF THE RAILROADS OF THE UNITED STATES FOR 1883, ETC., ETC. By Henry V. Poor. [16th Annual Number.] New York: H. V. & H. W. Poor, 70 Wall street. London: Effingham Wilson, Royal Exchange, 1883.

Poor's Manual of Railroads has come to be looked upon as a standard work of reference for information, statistical, historical and descriptive, respecting the railroads of the United States. For all having business or other relations required a knowledge of the mileage, stocks, bonds, cost, traffic, earnings, expenses, organization, etc., of the railroad companies of this country, the work is simply indispensable. The sixteen annual volumes which Mr. Poor has issued form an exceedingly valuable history of the rise, progress and present status of the railroad systems of the United States.

TWENTY YEARS WITH THE INDICATOR. By Thomas Pray, Jr., M.E., C.E. Boston: Boston Journal of Commerce Co., 128 Purchase street. 1883.

This work comprises 162 pages and 95 illustrations, and contains an account, in such form as to be intelligible to one unfamiliar with the subject, of the author's experience of twenty years in the use and application of the indicator in correcting and improving the economical efficiency of steam engines. It is illustrated by numerous diagrams, as mentioned above.

These diagrams are engraved to scale, and most of them have been taken from actual practice, produced just as they left the indicator, from marine and stationary engines.

The indicator diagrams, simple as they are to those who understand how to read them, are, unfortunately, a sealed book to only too many engineers.

This work, however, by its lessons, shows plainly the difference between good and bad diagrams as they are selected from the twenty years' practice of the author, with reference to the special business in hand, and any person who is operating with steam as a motive power may read it with profit. W. B. L.

Franklin Institute.

[*Proceedings of the Stated Meeting, held November* 21, 1883.]

HALL OF THE INSTITUTE, Nov. 21, 1883.

The meeting was called to order at the usual hour, with the President, Mr. Wm. P. Tatham, in the chair.

There were present 92 members and 16 visitors.

The minutes of the previous meeting were read and approved. The Actuary submitted the minutes of the Board of Managers, and reported that at the stated meeting held Wednesday, November 14th, 13 persons had been elected to membership.

The Secretary, by instruction from the Committee on Science and the Arts, reported that the Committee had recommended the award of the Scott Legacy Medal and Premium to Messrs. Blodgett Brothers & Tirrell, of Boston, for their improvements in Electric Signal Clocks, and to Arnold Nacke, of Philadelphia, for his improvement in Screw Cutting Devices. He also reported that the same had been advertised for three months in the JOURNAL, and that he had received no objections thereto.

Mr. J. E. Mitchell, seconded by Hector Orr, moved that the recommendation of the Committee to award the Scott Legacy Medal and Premium to Blodgett Brothers & Tirrell, for their improvment in Electric Signal Clocks, be approved, and that the Secretary be directed to notify the Committee of Minor Trusts of the Board of City Trusts of the action of the Institute. Carried.

A similar motion, by the same movers, was made on behalf of Mr. Arnold Nacke, for his improvement in Screw Cutting Devices, which was also carried.

Mr. J. E. Mitchell then moved to suspend the usual order of business, in order to permit action to be taken respecting the recent death of Mr. Edwin Greble, of Philadelphia, for many years a member of the

Institute. The motion was carried. Mr. Mitchell thereupon made the following remarks:

"MR. PRESIDENT:—It becomes my painful duty to announce to the Institute the death of one of its oldest and most useful members—EDWIN GREBLE—who died October 23d, in the 78th year of his age.

"Mr. Greble was elected a member of the Institute in 1833, only nine years after its organization, and has been an honored member for over fifty years.

"From the time of his election, in 1833, up to 1864, Mr. Greble was one of the most active workers in the management of the Institute, having served on several important committees, and for nearly a quarter of a century, from 1841 to 1864, was an active member of the Board of Managers, and its chairman in 1848.

"Almost his only living colleague at this time is Mr. Frederick Fraley, who bears testimony to the great value of his services at this early period, and of his entire devotion to the best interests of the Institute.

"Mr. Greble was always a loyal citizen of Philadelphia, his native city, his son, Lieutenant Greble, being one of the first to fall in the defence of the Union.

"He was honored by a seat in our City Councils in 1862, and was chairman of the committee to disburse the money provided to aid in furnishing soldiers during the late war, and many thousands of dollars passed through his hands. He was elected a Trustee of the Pennsylvania Museum and School of Industrial Art, and took a deep interest in everything calculated to improve the taste and elevate the condition of the working people, many beautiful monuments and other works in marble and granite remaining as the result of his taste. I therefore beg leave to offer the following:

"*Resolved*, That in the death of Edwin Greble, which occurred on 23d of October last, in the 78th year of his age, the Franklin Institute has lost one of its earliest and most useful members, one who by his actions, aid and counsel in the early days of the Institute did much to lay the foundations on which rest its present high position of usefulness, and who secured the respect of his colleagues in after years by his hearty co-operation in carrying forward its work.

"*Resolved*, That his fellow-members hereby tender to his family their respectful and heartfelt sympathy."

The resolutions were adopted without dissenting voice.

The Secretary's report embraced remarks upon the amendments to

the British Patent Law, which go into effect on January 1, 1884; the project for a second ship canal across the Isthmus of Suez; the general adoption throughout the United States of the New Standard of time; a description of an improvement in Saddles by Mr. P. McFadden, of Philadelphia; of certain improvements in the construction of Organs by Prof. Gally, of Boston, which were described by Mr. William Blasius; of an automatic device invented by P. E. Jay, of New York, for preventing the freezing of water pipes, consisting of a valve in the water pipe placed above the point at which there may be danger of freezing, and so adjusted that before the weather becomes cold enough to freeze the water in the pipes, the valve is automatically opened, a flow of water is established through the pipe, and the same thus protected; and of an automatic cut-out, devised by Messrs. Pinkham & Seal, of Philadelphia, and designed to preserve an open circuit battery from injury when accidentally close circuited for any length of time, and which will again make proper connections when the ground has been removed.

A strong magnet, of low resistance, controls an armature, which in turn operates an insulated cylinder by means of a connecting rod. Attached to the upper end of this cylinder is the segment of a cog-wheel, which engages in a smaller one bearing a fan, the object of which is to offer sufficient resistance to the armature to cause it to move slowly.

The outer surface of this same cylinder, which is about $\frac{5}{8}$ inch in diameter, and about 1 inch long, is faced with platinum, against which three fingers, secured to a post of rubber or other insulating substance, come in contact. These fingers are made of a good conductor, possessed of more or less elasticity. The first finger plays upon the platinum surface above described the entire limit of its partial revolution, caused by the action of the armature. The second finger plays upon the platinum until the armature is drawn nearly up to the magnet heads, when it becomes insulated by a piece of rubber passing under it.

The third finger is the reverse of the second, being insulated from the cylinder until just before the second finger becomes disconnected, when it comes into contact with the platinum surface. No. 1 finger is connected with one wire of the magnet, the other wire being attached to a binding post in the instrument.

Fingers Nos. 2 and 3 connect with two more binding posts. A

weight is secured to the cylinder in such position that when the magnet ceases to be energized the armature is carried back to its normal position.

The instrument is attached as follows: The magnet is looped into the ground wire of the battery by means of two of the binding posts. This disposes of fingers 1 and 2, which are always in contact on the platinum surface when the magnet is not energized. The other binding post is attached by wire to the same pole of a gravity battery which corresponds to the ground wire of the open circuit battery. The other pole is attached to same wire of the opposite pole of open circuit battery. This disposes of No. 3 finger. The action of the instrument is now very simple. Any vibratory connection, such as ringing a bell or lighting an automatic gas burner has no effect whatever upon the instrument. A single contact, such as is caused when ringing a stroke or tap bell or lighting a burner by the wire spark (so called), produces a slight impulse in the instrument; but should the contact be sustained for one-fourth of a minute, the energized magnet attracts the armature which revolves the insulated platinum surface, causing a change of connections. When at rest, fingers 1 and 2 are in contact. When energized, fingers 1 and 3 are in contact. No. 2, which connects with open circuit battery, has now become insulated, and No. 3 which connects with closed circuit battery has come into contact with No. 1, or ground wire. In this instrument the ground is not removed, but the circuit is simply changed from a battery which will be destroyed if grounded a sufficient length of time, to a battery whose nature is the reverse, and would therefore carry the ground without destruction so long as it has material to work upon. To preserve the closed circuit battery in a normal condition while not in use, it is close circuited through a coil of very high resistance which allows just enough current to pass through the battery to retain its strength.

Now, should the ground be removed by accident or otherwise, the magnet loses its energy and the armature is carried back to its normal position by the weight on the cylinder. The instrument is actuated upon by the open circuit battery up to a certain point when the closed circuit battery is thrown in and retains the armature at that point until the ground is removed, thus opening the circuit of the destructible battery.

The instrument is enclosed in a neat box about the size of a transmitter box, and has a glass front exposing to view a needle which points to the words "grounded" and "clear" according as the instrument is

so operated upon. The box is locked to prevent tampering or mischief and the binding posts are secured to the upper end of the base which projects somewhat beyond the box itself.

Professor Edwin J. Houston being called upon by the Secretary to explain the invention of Mr. Patrick B. Delany, of the Synchronous Multiplex Telegraph System, remarked:

"It gives me great pleasure, Mr. President and gentlemen of the Institute, to call your attention to what I cannot but regard as the most wonderful electrical invention of the present time. I refer to the system of Synchronous Multiplex Telegraphic communication mainly the invention of Mr. Patrick B. Delany.

"You will the more readily appreciate the great value of this invention when I tell you that the only system of quadruplex telegraphy, by means of which no more than four messages can be simultaneously transmitted on one and the same wire, has hitherto been owned and operated solely by the Western Union Telegraph Company, and is justly regarded by that company as its most valuable invention. What then must be the value of Mr. Delany's invention, by means of which no less than seventy-two messages can be simultaneously transmitted on the same wire.

It will be almost impossible for me to give you a full description of this remarkable invention without the aid of drawings and apparatus, but I will do my best, leaving minor details to a paper which I will shortly publish in the JOURNAL of the Institute.

"The Synchronous Multiplex System differs essentially from the present quadruplex system, which, as you well know, is based on the balancing of resistances, whereby the transmitting operator's instrument is unaffected by the messages transmitted, but is ready for the reception of signals from the other end of the line.

"Mr. Delany's system, however, is based on the synchronous rotation of two discs, one at each end of the line, by means of which a single wire, constituting the line, is brought simultaneously into connection with corresponding operating instruments at each end of the line, and transferred from one set of instruments to another so rapidly that the operator transmitting or receiving does not realize that the line has been disconnected from one instrument and given to another, since each operator always has the line at his disposal, even at the highest rate of manipulation.

"It will therefore be understood that the synchorous system is based

on the following simple fact; viz., that the time during which any telegraphic operator is actually using the line bears an exceedingly small ratio to the time that the line is out of use; and that in this system each operator follows the preceding operator, and uses the line only when it is not required by others. Although we speak of say seventy-two messages simultaneously transmitted on the same wire, yet, in point of fact, only one operator is using the line at any given time. The effect, however, is practically the same as if it were simultaneously used by all the seventy-two operators, since, if a single wire, connecting, say New York and Philadelphia, had seventy-two branches running from the terminus at Philadelphia, to seventy-two distinct operators in Philadelphia, and seventy-two branches running from the New York terminus to seventy-two distinct operators in New York, any seventy-two of these operators could, at any time, have the line at their disposal to the same extent as if it were a private line, entirely irrespective of whether any or all of the other operators were using it, since no two of them are given the line at exactly the same time.

"The practical success of this system is dependent on the ability to maintain perfect synchronism between the rotating discs at each end of the line. By the application of a beautiful system of perfectly automatic regulations the inventor has succeeded in obtaining this so thoroughly that the two discs can be maintained in continuous motion for days without varying from one another by as much as the six hundredth part of a second. This he effects by a series of electrical impulses sent over the same wire that connects the distant stations, at such times only that one instrument is slightly in advance of the other. Should the line connecting the two stations be accidentally broken, the synchronism between the two instruments would of course be lost, but since the control is entirely automatic, they would place themselves in synchronism with one another as soon as the line was connected.

"Although the mechanism requisite to produce these results is necessarily somewhat complicated, yet the extent of the complexities is by no means as great as might be believed necessary. Indeed, much less skill is required to keep the line in running order, than is requisite with the ordinary quadruplex system, for in the quadruplex system a change in the electrical condition of the line equivalent to a lengthening of the circuit for say ten miles, will throw the apparatus out of adjustment and stop all communication, while in the multiplex, as I myself have seen, an instantaneous change in the resistance of the line

equal to five hundred miles, may be made without practically affecting the synchronous movement of the distributers, or interrupting the various circuits.

"A marked advantage of the synchronous system of telegraphy, over those now in use, is in the absolute secrecy. No tapping of a synchronous line can by any possibility disclose the nature of the intelligence being transmitted, since the line at the point tapped would then give not only all the messages it was then transmitting, but also the separate makes and breaks caused by the successive transference of the line to each of the operators connected therewith.

"In order to prevent the breaks caused by the successive transferrence of the line to the different operators from affecting the instruments at the other end, a very beautiful use is made of the well-known polarized relay, by means of which the operators' instruments respond not to changes in the continuity of the circuit, but to changes in the polarity of the sending instruments that are placed in the circuit of a split battery.

"This invention is due to Mr. E. A. Calahan, the inventor of the stock exchange printing telegraph, who has been associated with Mr. Delany in his inventions."

The report of the Joint Committee on the reading of Papers was then called up as the special business of the evening. After some discussion of the same, Mr. J. M. Eldridge moved the addition, at the close of resolution authorizing the Secretary to provide a signal bell, etc., of the words, "for a certain number of minutes." The same was approved.

Prof. E. J. Houston, seconded by Mr. Washington Jones, moved that so much of the report of the Committee as related to the alterations of the by-laws be indefinitely postponed, and that the remainder of the report be approved and adopted. Carried.

The report of the Special Committee on the "Examination of Steam Engineers," presented majority and minority reports. After much debate thereon, it was finally decided, on motion of Mr. J. W. Nystrom, to recommit the reports to the Committee, and to increase the number of its members from five to seven. The President appointed as additional members, Messrs. William A. Ingham and William Helme.

The meeting was thereupon adjourned.

WM. H. WAHL, *Secretary.*